RCRA Facility Investigation
Phase IA Report
CIBA – GEIGY Facility
Cranston, Rhode Island

Volume 1 of 2

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Executive Summary

EXECUTIVE SUMMARY

This section summarizes the Phase IA Report on the RCRA Facility Investigation (RFI) for the CIBA-GEIGY facility at Cranston, Rhode Island.

OVERVIEW

Phase IA of the RFI was conducted primarily in July and August 1990 and involved four studies:

- a geophysical investigation;
- a geological investigation;
- a hydrogeological investigation; and
- a hydrological investigation.

Goals of Phase IA

Overall, the Phase IA studies were conducted:

- to evaluate contaminant migration pathways at and near the facility;
- to characterize ground water conditions at the facility;
- to characterize the geology, including the subsurface features and obstructions, at the facility; and
- to characterize the Pawtuxet River and its potential for transporting site-related contamination.

All these goals serve to fine-tune the Release Characterization Program -- Phase IB of the RCRA Facility Investigation -- and are elaborated in Section 1.3 of the Report.

Impact of Phase IA

As a result of the findings from the four Phase IA investigations:

- o no major changes to the RFI Work Plan will be required; and
- o no work will be deleted from the Work Plan; but
- o some additional work will be required to characterize the site stratigraphy and ground water hydraulics further.

Data Collected But Not Used in this Report

Some supplementary physicochemical data collection occurred during Phase IA as an adjunct to the investigations. These supplementary data collected in Phase IA will be carried forward and compared with data collected in Phase IB. These supplementary data include:

- o headspace analysis (field screening) of soil samples;
- o cation exchange capacity, total organic carbon, and Ph of soil and sediment samples; and
- o collection of undisturbed samples for hydraulic conductivity, bulk density, porosity, and grain size.

Even though not specifically part of the Physical Characterization, the results of the headspace analysis suggested the following minor change in the Phase IB Work Plan:

- o Soil samples from a new boring near P-21D will be analyzed for Appendix IX volatile organic compounds in order to investigate further the anomalous headspace results detected in samples from P-21D.

This change to the Work Plan is discussed in Section 1 of this Report.

Limitations of the Phase IA Geotechnical Data

As part of the Phase IA investigation, soil and riverbed sediment samples were obtained and submitted for geotechnical analyses (e.g., grain size, porosity, bulk density, and hydraulic conductivity). Although the geotechnical data from those analyses are reported in this document, some of the samples were not analyzed according to the procedures described in the project QA/QC Plan. Specific nonconformances included:

- o validation (through reasonableness) of results not performed by the laboratory;
- o grain size analyses not performed according to the ASTM sieves procedures specified in the QA/QC Plan; and,
- o selected undisturbed soil samples were re-molded prior to analysis.

Because of these departures from the approved QA/QC procedures, some of the geotechnical data is suspect. These suspect data created data gaps in the Phase IA investigation; these data gaps will be resolved in Phase IB. Corrective actions have been established to correct these deficiencies in future sampling.

Organization of this Executive Summary

The rest of this executive summary provides additional details supporting these conclusions, organized around the geophysical, geological, hydrogeological, and hydrological investigations conducted in Phase IA. Each investigation is described briefly by addressing these topics:

- o the purposes of the investigation;
- o the results of the investigation; and
- o the impact of the investigation on the Phase IB Work Plan (if any).

Sections of the Report that provide details on each topic are referenced throughout this summary.

THE GEOPHYSICAL INVESTIGATION

The geophysical investigation entailed three surveys -- a seismic refraction survey, an electrical resistivity survey, and a ground-penetrating radar survey.

Purposes of the Geophysical Investigation

Both the seismic refraction survey and the electrical resistivity survey were performed:

- to evaluate the depth to bedrock;
- to evaluate the depth to the saturated zone;
- to evaluate depths and thicknesses of the stratigraphic units within the overburden; and
- to corroborate data collected from the drilling program in the geological investigation.

The ground-penetrating radar survey was performed:

- to locate and map shallow subsurface features (e.g., foundations, utilities, trenches) at the facility that could affect ground water flow and/or contaminant migration; and
- to evaluate shallow unconsolidated deposits at the facility.

The methods and analyses used in performing the three surveys in the geophysical investigation are described in detail in Section 2.3 of the Report.

Results of the Geophysical Investigation

The geophysical investigation provided the following information:

- The depth to bedrock beneath the facility averages 50 to 60 feet.
- The average depths to bedrock in the three study areas of the facility were as follows:
  - -- Production Area: 50 to 60 feet below land surface;
  - -- Waste Water Treatment Area: 45 to 60 feet below land surface; and
  - -- Warwick Area: 60 feet below land surface.
- A dense till of varying thickness overlies the bedrock.
- The average thicknesses of till in the three study areas of the facility were as follows:
  - -- Production Area: 10 to 15 feet;
  - -- Waste Water Treatment Area: 10 to 30 feet; and
  - -- Warwick Area: 20 to 30 feet.
- The overburden deposits -- consisting of fine silts, sands, clays, and some gravels -- were characterized by gradational facies changes both horizontally and vertically.
- The ground-penetrating radar survey did not locate any significant subsurface features at the site that could affect ground water flow and/or contaminant migration.
- The electrical resistivity survey was more effective than the seismic refraction survey in discriminating bedrock, till, and individual units of the overburden deposits.

The results obtained from the geophysical investigation are described in Section 2.4 and discussed in Section 2.5 of this Report.

THE GEOLOGICAL INVESTIGATION

The geological investigation entailed three activities -- a literature review, field mapping of bedrock exposures, and an on-site geological characterization.

Purposes of the Geological Investigation

Both the literature review and the field mapping of bedrock exposures were conducted to characterize the geological environment of the region, the locale, and the facility itself. The on-site geological characterization program included drilling and sampling subsurface sediments and bedrock. Data from the drilling program were used to evaluate the overburden stratigraphy and rock lithologies. Bedrock cores were evaluated and correlated with off-site exposures; sediment samples were tested for physical properties that could affect contaminant migration, and also were field-screened for volatile organic compounds.

The methods and analyses used in performing the three tasks in the geological investigation are described in detail in Section 3.3 of the Report.

Results of the Geological Investigation

The geological investigation provided the following information:

- Bedrock beneath the facility consists of partially metamorphosed sandstones and shales, consistent with lithologies observed in of the Rhode Island Formation.
- Till was encountered (overlying bedrock) in several borings.
- The variable nature of the overburden deposits is consistent with a glaciofluvial and/or fluvial deposition.

- The overburden deposits are more complex than had been anticipated based on both preliminary results and previous data. Individual sediment units appear to be discontinuous both vertically and horizontally.
- High correlations were found between data from borings and data from the electrical resistivity survey.
- The till and bedrock have similar seismic velocities and could not be distinguished by the seismic refraction survey. Higher-density deposits overlie lower-density deposits in some areas, so the seismic refraction method is less effective in differentiating the overburden, till, and bedrock.
- The site geology is much more complex than had been anticipated, and the geological conceptual model of the site is not yet fully developed.

The results obtained from the geological investigation are described in Section 3.4 and discussed in Section 3.5 of this Report.

Impact of the Geological Investigation

The results of the geological investigation revealed data gaps that require additional work (not included in the RFI Work Plan), and also suggested one change to the Phase IB Work Plan. No work will be deleted from the Work Plan.

The geological investigation revealed the following data gaps which must be addressed by additional work:

- <u>The facility's overburden stratigraphy must be defined better.</u> To do so, three additional continuous sample borings will be advanced to the top of rock. One boring will be located in the northwest corner of the Waste Water Treatment Area; the other borings will be located in the western section of the Warwick Area.

- The overburden hydrostratigraphic conditions at the facility must be defined better. To do so, two additional continuous sample borings will be advanced off-site -- one north and the other west of the Waste Water Treatment Area. Both borings will be advanced to the top of rock.
- The grain size distribution of soil samples must be differentiated better. To do so, every second soil sample from borings advanced in Phase IB will be analyzed for grain size to differentiate between fine-grained (silts) and very fine-grained (clay) materials.
- Soil samples must be classified better. To do so, all soil samples submitted for geotechnical analysis in Phase IB also will be tested for Atterberg limits and moisture content.

These recommendations for additional work are described in Section 6.4 of this Report.

THE HYDROGEOLOGICAL INVESTIGATION

The hydrogeological investigation entailed three activities -- installing bedrock monitoring wells and overburden piezometers, monitoring ground water levels, and slug testing new wells and piezometers.

Purposes of the Hydrogeological Investigation

Installing bedrock monitoring wells and overburden piezometers was performed:

- to characterize the aquifer zones;
- to determine ground water flow directions and gradients; and
- to identify aquifer types and boundaries.

Ground water level monitoring was performed to evaluate variations in ground water elevation. Slug testing new wells and piezometers was performed to evaluate the hydraulic conductivities of the stratigraphic units. Data from the hydrogeological investigation will be used to select monitoring well locations for the Release Characterization Program (i.e., Phase IB).

The methods and analyses used in performing the three tasks in the hydrogeological investigation are described in detail in Section 4.3 of the Report.

Results of the Hydrogeological Investigation

The hydrogeological investigation provided the following information:

- o The bedrock aquifer appears to be confined, but the direction of ground water flow could not be determined.
- o There are significant upward potential gradients within the overburden.
- o The apparent horizontal potential gradients were determined as follows:
  - -- bedrock aquifer: 0.003 to 0.005;
  - -- deep overburden aquifer: 0.02 to 0.1; and
  - -- shallow overburden aquifer: 0.013 to 0.1.

The results obtained from the hydrogeological investigation are described in Section 4.4 and discussed in Section 4.5 of this Report.

Impact of the Hydrogeological Investigation

The hydrogeological investigation revealed data gaps that require additional work (not included in the RFI Work Plan) and also suggested changes to the Phase IB Work Plan. No work will be deleted from the Work Plan.

The hydrogeological investigation revealed the following data gaps which must be addressed by additional work:

- o <u>The ground water flow patterns, hydraulic gradients, and formation permeabilities of the underlying strata must be characterized better.</u> To do so, new stratigraphic borings (off-site) will be completed as deep piezometers. Shallow monitoring wells will also be installed to evaluate background water quality at these locations. On-site stratigraphic borings will also be completed as deep piezometers. A shallow piezometer will also be installed to establish a nested piezometer pair at one boring location.

- o <u>The site hydraulics must be evaluated better.</u> To do so, the following tasks will be performed:
  - -- In Phase IB, all existing monitoring wells and piezometers will be rehabilitated, as appropriate.
  - -- Water level measurements will be taken monthly, not quarterly.
  - -- Long-term automatic ground water level data logging will be performed in a few selected wells in the Production Area.
  - -- Small scale (i.e., short-duration, low rate) step drawdown tests will be performed in the Production Area.
  - -- Short-term constant rate pump tests will be performed on selected wells in the Production Area. The rate and duration for the tests will be determined based on the results of the step drawdown tests.

These recommendations for additional work are described in Section 6.4 of this Report.

The results of the hydrogeological investigation also suggested changes in the Phase IB Work Plan:

- o Minor locational changes will be made for monitoring wells intended to be downgradient of specific releases, based on our current (9/13/90) water table contour map.

- o Changes will be made to screen settings based on our understanding of the complex stratigraphy at the site and on the boring data now available.

These changes to the work plan are discussed in Section 6.3 of this Report.

THE HYDROLOGICAL INVESTIGATION

The hydrological investigation entailed five activities -- a literature review, a bathymetric survey, water discharge monitoring, sediment discharge monitoring, and riverbed sediment sampling and analysis.

Purposes of the Hydrological Investigation

The literature review was performed to provide background information concerning the Pawtuxet River and to evaluate the surface water bodies potentially affected by past facility releases. The bathymetric survey was conducted to evaluate potential riverbed sediment depositional areas. Water discharge monitoring was performed to determine if ground water discharge from the facility is quantifiable. Sediment discharge monitoring was performed to evaluate the transport of suspended sediment. Riverbed sediment sampling and analysis were performed to measure physicochemical parameters that affect bedload transport.

The methods and analyses used in performing the five tasks in the hydrological investigation are described in detail in Section 5.3 of the Report.

Results of the Hydrological Investigation

The hydrological investigation provided the following information:

- o Discharge values calculated from the three discharge monitoring events fall within the 30th through 70th percentiles range of the discharge frequency statistic reported for the USGS gauge at Cranston, Rhode Island.
- o Working rating curves were developed for the transects at the site.
- o Relatively low concentrations of suspended sediment were detected at both transects under all three observed flow conditions.
- o Bed sediment is primarily sands and gravels, except along the bulkhead where the samples were finer-grained.
- o No bedforms having amplitudes greater than six inches were observed.
- o The Froude number calculated for the maximum flow rate observed indicates that the observed river conditions are within the lower flow regime. Therefore, bedload sediment transport rates appear to be low under the conditions observed. The monitoring events did not include flood conditions.

The results obtained from the hydrological investigation are described in Section 5.4 and discussed in Section 5.5 of the Report.

Section One

SECTION 1
INTRODUCTION

1.1 OVERVIEW

This report summarizes information pertaining to Phase IA of the RCRA Facility Investigation for the CIBA-GEIGY facility in Cranston, Rhode Island. This section describes the history of the project and facility (Section 1.2), the goals of Phase IA (Section 1.3), mobilization for Phase IA (Section 1.4), and the organization of the rest of this report (Section 1.5). A summary concludes this section.

1.2 HISTORY

The history of this project and of the CIBA-GEIGY facility at Cranston, Rhode Island, are described here.

1.2.1 History of the Project

A draft Administrative Order on Consent (hereafter simply called the Order) requiring a RCRA Corrective Action Study at the Cranston facility was issued to CIBA-GEIGY on 30 September 1988. After negotiations and evaluation of public comments, the Order was signed by CIBA-GEIGY on 9 June 1989 and became effective on 16 June 1989.

The RCRA Corrective Action Process has four stages:

1) RCRA Facility Assessment;
2) RCRA Facility Investigation;
3) Corrective Measures Study Proposal; and
4) Corrective Measures Study Report.

USEPA conducted the RCRA Facility Assessment (hereafter simply called the Facility Assessment) of the site in 1987. The Facility Assessment included a review of background data, a site reconnaissance, and a sampling visit. Data were evaluated to make initial determinations on past facility releases. The results of the Facility Assessment appear in the "Final RFA Report, CIBA-GEIGY, RCRA Facility Assessment" (1988).

In 1988, additional studies were conducted by CIBA-GEIGY. A Preliminary Investigation of the facility was performed both to provide initial data on the facility's physical environment and to characterize selected past facility releases. The Preliminary Investigation was not required by the Order; rather, it was performed to provide the data needed to negotiate a comprehensive and site-specific Order. The results of the Preliminary Investigation are summarized in the <u>Current Assessment Summary Report</u> of the RCRA Facility Investigation Proposal (Volume 1, Chapter 1).

The RCRA Facility Investigation (hereafter, the Facility Investigation) is the second stage of the RCRA Corrective Action Process. The Facility Investigation characterizes the impact of known and/or suspected releases that were determined to require further action by the Facility Assessment. The Facility Investigation has two field investigation phases (Phase I and Phase II).

Phase I will be performed in two parts -- Phase IA and Phase IB. This approach provides an interim deliverable (the Phase IA Report). The Phase IA Report is not required by the Order. This phased approach, proposed by CIBA-GEIGY, provides for additional USEPA guidance throughout the process. In Phase IA, studies were conducted to characterize the facility's physical environment more completely. The results of these studies, along with modifications to the sampling strategies proposed for the Phase IB investigation, are the subject of this document. The Phase IB investigation will begin after USEPA reviews and approves this Phase IA Report.

Phase II of the Facility Investigation entails additional site characterization tasks and additional sampling of all media of concern. Media Protection Standards also will be proposed.

The third and fourth stages of the Corrective Action Process are the Corrective Measures Study (CMS) Proposal and the Corrective Measures Study (CMS) Report. Corrective measures to be evaluated for achieving the Media Protection Standards, and the justification for their selection, will be presented in the CMS Proposal. An assessment of the corrective measures proposed to meet the Media Protection Standards will be presented in the CMS Report.

1.2.2 History of the Facility

Chemical manufacturing occurred at the facility from 1930 to 1986. Until 1954, the Alrose Chemical Company occupied part of the present plant site. In 1954, the GEIGY Chemical Company of New York purchased the facility from the Alrose Chemical Company to operate as its new chemical manufacturing plant. In 1970, the GEIGY Chemical Company merged with Ciba Corporation of New Jersey to form the CIBA-GEIGY Corporation (incorporated in the State of New York). After the merger, the Cranston plant was used as a production facility for manufacturing organic chemicals on a batch basis. Major product categories (and the decades in which they were produced) included:

1950s - agricultural products, and leather and textile auxiliaries
1960s - plastics additives, optical brighteners, pharmaceuticals, and textile auxiliaries
1970s - pharmaceuticals, agricultural products, plastics additives, textile auxiliaries, and bacteriostats
1980s - pharmaceuticals and plastics additives

In January 1984, CIBA-GEIGY announced plans for a gradual phase-out of the Cranston plant as part of an overall consolidation of CIBA-GEIGY's chemical manufacturing operations. As of May 1986, CIBA-GEIGY had ceased all chemical manufacturing operations at the facility and began decommissioning and razing the plant.

1.2.3 Solid Waste Management Units (SWMUs), Areas of Concern (AOCs), and Additional Areas of Investigation (AAOIs)

Based on information submitted by CIBA-GEIGY to the USEPA and on information gathered by the USEPA (including the Facility Assessment), twelve SWMUs and two AOCs have been identified at the facility. Information about these SWMUs and AOCs is summarized in Table 1-1. The locations of the SWMUs and AOCs, and the media to be investigated for each, are shown on Figure 1-1.

CIBA-GEIGY has identified two Additional Areas of Investigation (AAOIs) for completeness of study. No releases from those AAOIs are known, but the potential for a release may have existed in the past. The Additional Areas of Investigation have been designated AAOI-15 (the Laboratory Building Waste Water Sump) and AAOI-16 (the Maintenance Department Cleaning Area). Information on the AAOIs also is summarized in Table 1-1 and shown on Figure 1-1.

Details on the history of the project and the facility, and on past known and suspected facility releases, are provided in the Current Assessment Summary Report of the RCRA Facility Investigation Proposal (Volume 1, Chapter 1).

1.3 GOALS OF PHASE IA

The Preliminary Investigation of the Cranston facility was conducted by CIBA-GEIGY to develop an initial physical model of the site. Review and evaluation of the information from the Preliminary Investigation revealed data gaps. In Phase IA, additional studies were conducted to supplement existing data about the site and to provide a better understanding of the facility's physical environment. Some supplementary physicochemical data were collected in Phase IA but were not used in this report. These data will be carried forward and compared to data collected in Phase IB.

Phase IA included four investigations -- geophysical, geological, hydrogeological, and hydrological. Evaluating the results of the Phase IA investigations permitted refining the sampling strategies proposed for the Release Characterization Study (Phase IB). The objectives for the Phase IA investigations are described here.

Geophysical Investigation. Three geophysical surveys were performed to characterize the subsurface conditions at the site. Two of the surveys -- a seismic refraction and an electrical resistivity survey -- were performed to evaluate the depth of bedrock, the depth of the saturated zone, and the depths and thicknesses of the stratigraphic units within the overburden. Data from these two surveys also were compared with information collected from the drilling program (part of the Geological Investigation). A ground-penetrating radar (GPR) survey also was performed at the facility to locate shallow subsurface features that could affect ground water flow or contaminant migration. Data collected in the GPR survey were used to locate and map the site's subsurface features (e.g., foundations, utilities, and trenches) and to evaluate the facility's shallow unconsolidated deposits.

Geological Investigation. Three activities were performed to characterize the regional, local, and facility geological environments. Two activities -- a literature review and field mapping of bedrock exposures -- were conducted to characterize the regional and local geomorphology, surficial geology, bedrock lithology, and bedrock structure. Data from these two activities were used both to develop a model of the area and to assess the facility-specific geological characteristics. The third activity -- on-site geological characterization -- included drilling and sampling subsurface soils and bedrock. The data from this activity were used to evaluate the overburden stratigraphy and rock lithologies. Bedrock cores were evaluated and correlated with off-site exposures. Soil samples were tested in the laboratory for physical properties that could affect contaminant mobility, and also were screened in the field for volatile organic compounds.

Hydrogeological Investigation. Three activities were performed to evaluate the facility's hydrogeological conditions. First, bedrock monitoring wells and overburden piezometers were installed to characterize the bedrock and water table aquifers, to determine ground water flow directions and gradients, and to identify aquifer types and boundaries. Second, water levels were monitored to evaluate variations in ground water flow. Third, new wells and piezometers were slug tested to evaluate the hydraulic conductivities of the stratigraphic units. Data from all three activities were used to select monitoring well locations for the Release Characterization Study (Phase IB).

Hydrological Investigation. Five activities were performed to evaluate the physical environment of the Pawtuxet River. First, a map study review was conducted to identify the surface water bodies potentially affected by past facility releases. Second, a bathymetric survey was performed to evaluate riverbed cross-sections and possibly sediment depositional areas. Third, water discharge monitoring was performed to determine if ground water discharge from the facility is quantifiable. Fourth, sediment discharge monitoring was performed to evaluate suspended sediment transport. Fifth, riverbed sediments were sampled and analyzed for physicochemical parameters.

1.4 PHASE IA MOBILIZATION

This section describes the mobilization activities that were performed before beginning the Phase IA field investigations. In general, subcontractors were hired, the site was staged to accommodate the investigation, and the scope of work was established. The specific mobilization activities were as follows:

- o A field office was established at the Cranston facility. Contractors were hired, permits were obtained, and part of the existing warehouse was refurbished as a field office. The necessary utilities (e.g., electrical, water, telephone) also were installed.

- o A drilling contractor was selected and scheduled. The scope of work was determined, well materials were obtained, and subsurface utilities were located.
- o The scope of analytical work was established with the laboratory. Bottle sets were ordered and lab time was scheduled.
- o Health and safety training was scheduled and conducted for the GPR contractor, CIBA-GEIGY employees, and field support contractors.
- o The site was gridded for the GPR survey. A 10-by-10 foot grid was established in the Production Area; a 20-by-20 foot grid was established in the Waste Water Treatment and Warwick areas.
- o A blasting contractor was hired to detonate charges for the seismic refraction survey. Blasting permits were obtained from the cities of Cranston and Warwick.
- o Decontamination pads were designed and built in each of the three study areas. Three two-thousand gallon storage tanks were ordered, built, and installed at each of the decontamination pads. These tanks will be used to store drilling fluids, decontamination water, purge water, and development water temporarily until disposal options have been selected.
- o River transects were established on the banks of the Pawtuxet River for both the bathymetric survey and the water discharge monitoring events.
- o The contractors for the river investigation were selected and scheduled.
- o Finally, the scope of work for the Phase IA investigation was finalized with USEPA.

1.5 ORGANIZATION OF THIS REPORT

The next four sections of this report describe the geophysical investigation (Section 2), the geological investigation (Section 3), the hydrogeological investigation (Section 4), and the hydrological investigation (Section 5). The objectives, methods and analyses, and results obtained are presented for each investigation, along with a discussion of the results. Conclusions, impact of the results from these four Phase IA investigations, and recommendations are presented in Section 6. When reading this document, please note the following:

- Terms, acronyms, and abbreviations are defined in Appendix A.
- The figures in this document reflect the best information about the facility and its environs that is currently available from the listed sources.
- Tables and figures are numbered within each section.
- Tables and figures appear following the text for a section. Tables appear first; some tables have multiple pages. Figures appear after the tables.

1.6 SUMMARY

This section reviewed the history of both the project and the facility, along with the goals of Phase IA. Mobilization efforts in Phase IA were summarized, and the organization of the rest of this report was presented. The next section describes the Phase IA geophysical investigation.

TABLE 1-1
SOLID WASTE MANAGEMENT UNITS, AREAS OF CONCERN AND ADDITIONAL AREAS OF INVESTIGATION
CIBA-GEIGY FACILITY
CRANSTON, RHODE ISLAND

Number	Type	Study Area	Active Dates	Location	Description
Solid Waste Managment Units (SWMUs)					
1	Hazardous waste storage area	Warwick Area	1981-1986	Northing: 248,975 Easting: 524,935	The hazardous waste storage area was designed for a maximum capacity storage of 768 55-gallon drums. Typically, this unit contained 300 to 400 drums. Various wastes were stored within this unit including: flammable liquids and solids, corrosive liquid and solids, organic mixtures and solids, non-hazardous organic mixtures and chloroform. The area was asphalt lined, diked and surrounded by a 6 ft high chain-link fence. The storage area was approximately 42 ft by 58 ft. The dike was capable of holding 48,000 gallons.
2	6000-gallon hazardous waste storage tank	Production Area	1981-1986	Northing: 249,130 Easting 523,860	The 6000-gallon above ground tank was used to provide storage of process wastes containing acetone, toluene, monochlorobenzene, isopropanol, naptha, xylene, heptane, methanol and water. The carbon steel tank was 17 ft high, had a diameter of 8 ft, and was enclosed by an 8000-gallon capacity dike (14.5 ft x 19 ft x 4 ft high).
3	7500-gallon, 90-day accumulation tank	Production Area	1985-1986	Northing: 249,110 Easting: 523,890	The vertical above ground tank, which had a capacity of 7500 gallons, was used to store flammable liquids for periods of less than 90 days. The stainless steel tank was 17 ft high, had a diameter of 8.5 ft, and was enclosed by a 25,000-gallon dike (approximately 28 ft x 29 ft x 4 ft high).

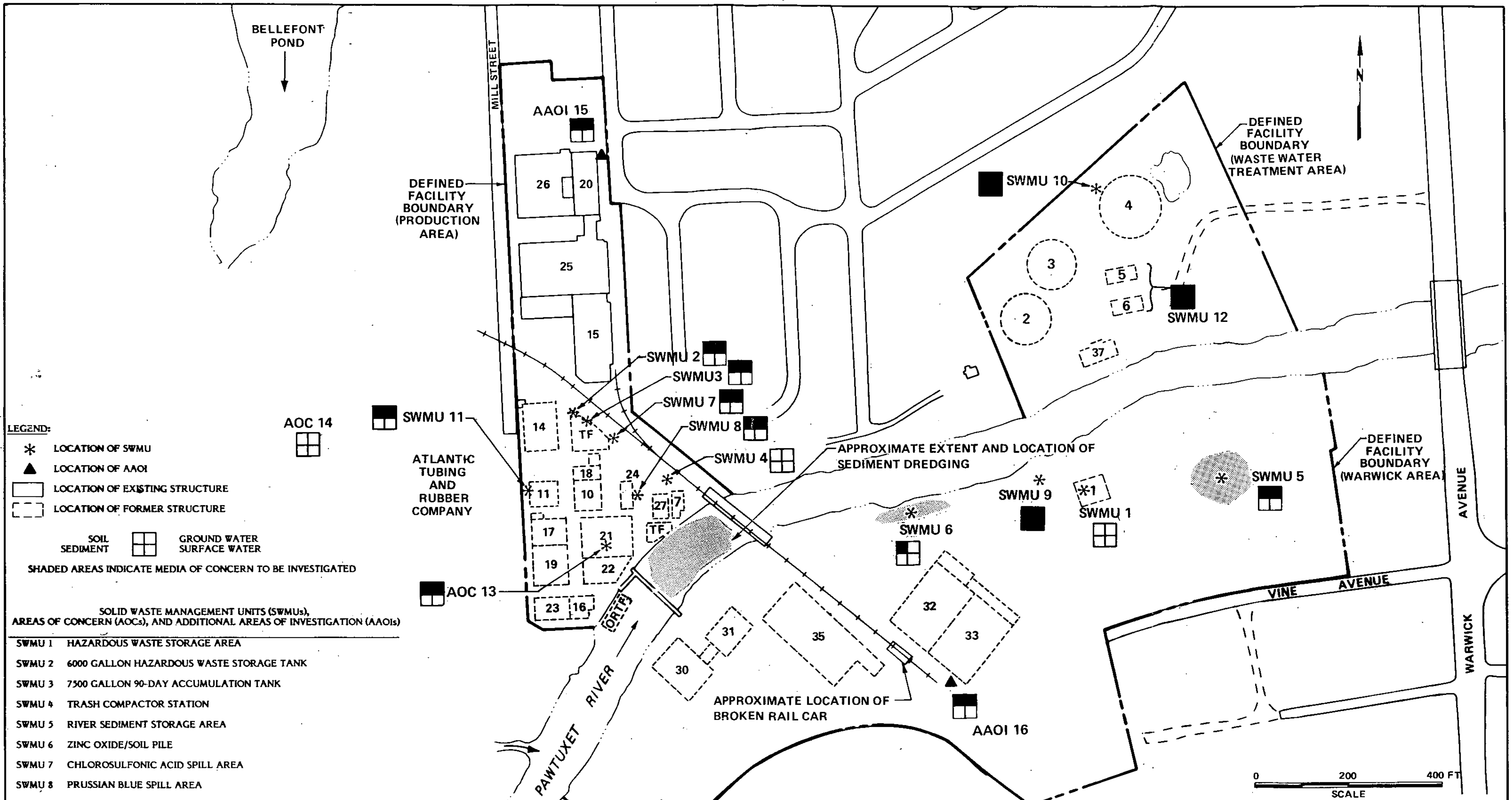
Number	Type	Study Area	Active Dates	Location	Description
4	Trash compactor station	Production Area	1972-1986	Northing: 249,050 Easting: 524,010	The trash compactor station had two compactors of 30 and 55 cubic yard capacity, and only handled packaging material paper wastes and washed fiber drums. The trash compactor area (21 ft x 36 ft) was concrete lined and drained to the waste water treatment plant.
5	River sediment storage area	Warwick Area	1971-1976	Northing: 249,020 Easting: 525,220	Approximately 6630 cubic yards of sediment dredged from the Pawtuxet River was piled in this area. The sediment was dredged as part of the removal of the original cofferdam/waste water outfall. The sediment was removed from the site in 1976. The natural grade of this area was restored in 1977.
6	Zinc oxide/soil pile	Warwick Area	Late 1960's to present	Northing: 248,920 Easting: 524,615	Approximately 25 cubic yards of soil containing about 10 percent zinc oxide residue exists on site. The zinc oxide residue was from an incident involving a broken railcar. The soil pile is approximately 50 ft long by 7 ft wide by 2 ft high.
7	Chlorosulfonic acid spill area	Production Area	1961	Northing: 249,080 Easting: 523,955	Approximately 500 gallons of chlorosulfonic acid were spilled over an area about 10 ft x 20 ft.
8	Prussian Blue spill area	Production Area	1956	Northing: 248,975 Easting: 523,990	Blue-stained soil, believed to be from Prussian Blue, resulted from a spill of unknown quantity. About 300 cubic yards of that soil were excavated and subsequently removed.

Number	Type	Study Area	Active Dates	Location	Description
9	Waste water pipeline break	Warwick Area	12 Jan 1982	Northing: 249,010 Easting: 524,840	A break in the main raw waste transfer line resulted in the discharge of about 24,000 gallons of waste water. The waste water entered the surface water runoff catchment system and discharged to the Pawtuxet River. The waste water typically contained halogenated and non-halogenated solvents and other organic compounds routinely used in the chemical manufacturing process.
10	Waste water pipeline break	Waste Water Treatment Area	7 Sept 1983	Northing: 249,575 Easting: 524,955	A break in an underground waste water line resulted in a discharge of about 50,000 gallons. The discharge flowed into a small on-site pond and then diverted to the Pawtuxet River. The pH of the released waste water was 8.5; the chemical oxygen demand (COD) was 1010 ppm. This discharge contained acetone (31 pounds), isopropyl alcohol (45 pounds), toluene (7 pounds), xylene (1.7 pounds), zinc (0.25 pounds), and nitrobenzene (0.125 pounds).
11	Toluene spill area	Production Area	1983	Northing: 248,990 Easting: 523,770	The estimated loss of toluene associated with this SWMU is between 9 and 90 pounds. The loss occurred via a subsurface sump associated with Building 11.
12	Waste water treatment plant	Waste Water Treatment Area	1970-1983	Northing: 249,405 Easting: 525,015	This area formerly was occupied by the waste water treatment plant. Biological trickling towers were used and periodic sump overflows from these towers resulted in discharges to the river. Influent to the trickling towers rountinely contained volatile and semi-volatile organic compounds. Additional releases from SWMU-12 in excess of the NPDES permit requirements have been reported for zinc, BOD, and phenols. For two releases, chloroform was discharged to the river.

TABLE 1-1 (Continued)
SOLID WASTE MANAGEMENT UNITS, AREAS OF CONCERN AND ADDITIONAL AREAS OF INVESTIGATION
CIBA-GEIGY FACILITY
CRANSTON, RHODE ISLAND

Number	Type	Study Area	Active Dates	Location	Description
Areas of Concern AOCs:					
13	Process building area	Production Area	1930-1986		Area in which most of the production activities occurred.
14	Atlantic Tubing and Rubber Company property	Adjacent to and and west of the Production Area	1981-present		This property was never used or developed by CIBA-GEIGY.
Additional Areas of Investigation (AAOIs):					
15	Laboratory building waste water sump	Production Area	1961-1987		The sump functioned as part of normal operations within the laboratory building. The gravity sump drained to sewer lines that discharged to the POTW.
16	Maintenance department cleaning area	Warwick Area	mid 1960s-1986		Area in which steam cleaning of maintenance equipment occurred. Rinse water drained to nearby surface water catch basin.

NOTE: CIBA-GEIGY has identified the two Additional Areas of Investigation; no releases are known, but the potential for a past release existed.



LEGEND:

- * LOCATION OF SWMU
- ▲ LOCATION OF AAOI
- LOCATION OF EXISTING STRUCTURE
- LOCATION OF FORMER STRUCTURE

SOIL / SEDIMENT — GROUND WATER / SURFACE WATER

SHADED AREAS INDICATE MEDIA OF CONCERN TO BE INVESTIGATED

SOLID WASTE MANAGEMENT UNITS (SWMUs), AREAS OF CONCERN (AOCs), AND ADDITIONAL AREAS OF INVESTIGATION (AAOIs)

SWMU 1	HAZARDOUS WASTE STORAGE AREA
SWMU 2	6000 GALLON HAZARDOUS WASTE STORAGE TANK
SWMU 3	7500 GALLON 90-DAY ACCUMULATION TANK
SWMU 4	TRASH COMPACTOR STATION
SWMU 5	RIVER SEDIMENT STORAGE AREA
SWMU 6	ZINC OXIDE/SOIL PILE
SWMU 7	CHLOROSULFONIC ACID SPILL AREA
SWMU 8	PRUSSIAN BLUE SPILL AREA
SWMU 9	WASTE WATER PIPELINE BREAK - WARWICK AREA
SWMU 10	WASTE WATER PIPELINE BREAK - WASTE WATER TREATMENT AREA
SWMU 11	TOLUENE SPILL AREA
SWMU 12	WASTE WATER TREATMENT PLANT
AOC 13	PROCESS BUILDING AREA
AOC 14	ATLANTIC TUBING AND RUBBER COMPANY PROPERTY
AAOI 15	LABORATORY WASTE WATER SUMP
AAOI 16	MAINTENANCE DEPARTMENT CLEANING AREA

NOTES

1. STRUCTURE LEGEND IS INCLUDING IN THE RCRA FACILITY INVESTIGATION PROPOSAL, CHAPTER 1, FIGURE 3-1.
2. CIBA-GEIGY HAS IDENTIFIED TWO ADDITIONAL AREAS OF INVESTIGATION (AAOIs). THOSE AAOIs HAVE BEEN DESIGNATED AAOI-15 AND AAOI-16.

BASE MAP SOURCE: GEOD CORPORATION OF NEWFOUNDLAND, NEW JERSEY, MAPPED BY PHOTOGRAMMETRIC METHODS FROM AERIAL PHOTOGRAPHS. DATE FLOWN: 2 APRIL 1989

MEDIA TO BE INVESTIGATED FOR SOLID WASTE MANAGEMENT UNITS, AREAS OF CONCERN, AND ADDITIONAL AREAS OF INVESTIGATION CIBA-GEIGY FACILITY, CRANSTON, RHODE ISLAND.

WOODWARD - CLYDE CONSULTANTS

CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS

WAYNE, NEW JERSEY

DR. BY: KF	SCALE: 1:2400	PROJ. NO.: 87X4660
CK'D. BY: MH	DATE: 22 JUN 1989	FIG. NO.: 1-1

Section Two

SECTION 2
GEOPHYSICAL INVESTIGATION

2.1 OVERVIEW

Geophysical investigation techniques provide relatively quick and non-invasive preliminary reconnaissance methods for locating and evaluating physical and chemical subsurface features where actual excavation of the ground may be undesirable or potentially dangerous. Geophysical methods have been helpful in deciding where to concentrate investigative cleanup efforts on sites requiring RCRA Facility Investigations (Barinaga, 1990; Benson, et al., 1985).

This section of the Phase IA Report describes the geophysical investigation. Section 2.2 describes the types of geophysical surveys used and their specific objectives. Section 2.3 discusses the methods and analyses used in each survey. Section 2.4 presents the results of each survey. Section 2.5 discusses these results. Section 2.6 summarizes the results of the geophysical surveys. Detailed discussions of the analyses and results from each survey are presented in Appendix B. Computer output of the geophysical analyses is presented in Appendix C.

2.2 INTRODUCTION AND OBJECTIVES

The geophysical investigation was conducted in accordance with the Facility Investigation Work Plan in Volume 1 of the RFI proposal. Three geophysical survey methods were used in this investigation -- *seismic refraction*, *electrical resistivity*, and *ground-penetrating radar*. All three survey methods were used in all three study areas at the site. The objectives of each geophysical method are described here.

The seismic refraction survey was conducted to provide continuous profiles of the underlying soil and bedrock; the survey was conducted in October 1989 and July 1990. The electrical resistivity survey was conducted along the same traverses as the seismic refraction survey to evaluate the depth and thickness of the underlying stratigraphic units, to detect and locate the presence of perched water tables (anomalous aquifer properties), and to corroborate field data from the seismic refraction survey and the drilling program. The electrical resistivity survey was conducted in October 1989 and July 1990. The ground-penetrating radar survey was conducted in July 1990 to identify shallow natural and man-made subsurface features, if any, that might affect ground water flow, contaminant migration, or the choice of shallow sampling methods.

2.3 METHODS AND ANALYSES

The methods and analyses used for each of the three surveys are described here.

2.3.1 Seismic Refraction Survey

The seismic refraction survey used the following method and analyses.

Method

Seismic refraction is a reconnaissance tool used to determine the thicknesses and depths of geologic layers and their respective soil or rock types. The method relies on the fact that soil and rock have distinctive seismic wave velocity contrasts between bedding layers and that seismic wave velocity generally increases with depth. The method is most useful where soil and rock layers are flat-lying and the velocity contrast between layers is large, such as that between soil and bedrock. It is much less useful in areas where the sediment layers are interfingering or reworked through glaciofluvial processes, where the layers are tilted or deformed, or where the velocity decreases with depth in certain layers.

Seismic refraction data are obtained by imparting seismic source signals, or "shots", into the ground and measuring on a seismograph the travel time of direct and refracted compressional waves at geophones (motion sensors) spaced at regular intervals along a line on the surface. At a certain point along the line of geophones, the seismic wave that was partially refracted along the top of a faster layer will arrive before the direct wave. The distance from the shot to this point is related to the depth of the refracting layer because the travel time for the seismic wave is proportional to the compressional wave velocity of the refracting layer. The compressional wave velocity determined for each layer using seismic refraction can be correlated with its material properties, such as density and hardness. In turn, the soil or rock type is inferred from these material properties. For a more complete description of the seismic refraction method, refer to Dobrin (1976), Telford, et al. (1976), or Benson, et al. (1985).

The seismic source signal can be produced by hitting a steel plate on the ground with a sledge hammer, shooting a shotgun slug into the ground, or exploding small pieces of dynamite in shallow holes. This survey used dynamite as a source signal, detonated by a licensed blaster. For each shot, a zero-delay blasting cap was pushed into a small piece of dynamite, buried to a depth of one or two feet, and connected to a blasting box. An electrical signal from the blasting box exploded the cap and dynamite, and simultaneously started the seismograph timer. Generally, five shots were fired along each seismic line: one at each of the two ends of the line, one in the middle of the line, and one between the middle and each of the two end points.

Each seismic line consisted of 12 Mark Products geophones generally positioned at 20-foot intervals. Some geophones were spaced closer together or farther apart to allow for obstructions (trees, brush, etc.). The geophones were connected by cable to a 12-channel EG&G Nimbus Signal Enhancement Seismograph which produced a hard-copy printout of the travel times to each geophone.

The survey used eleven seismic refraction lines to provide a continuous profile of subsurface geological units and the top of the underlying bedrock. The first seven lines were completed in October 1989; the other four lines were run in July 1990. Three seismic refraction lines were run in the Production Area, five were run in the Warwick Area, and three were run in the Waste Water Treatment Area. Figure 2-1 shows the location of each line.

<u>Analyses</u>

The travel time data and time-distance plots for each seismic line, along with the elevations of all geophones and shots, were entered into the SIPT2 computer program (written by the U.S. Bureau of Mines). The computer program determined the velocity of each refracting layer using time-distance calculations and other procedures developed by Hobson (1966). Depths and thicknesses of identified refracting layers were derived using standard travel time analysis methods. The methods were refined, where possible, by iterative ray-tracing techniques (Scott, 1972; Yacoub, 1970). The results were presented as cross-sections depicting the depths of the refracting layer(s) beneath each line. Geological data from borehole sampling were compared to the cross-sections to aid in data interpretation. (These comparisons are discussed in Section 3.0.)

2.3.2 Electrical Resistivity Survey

The electrical resistivity survey used the following methods and analyses.

Method

Electrical resistivity is a reconnaissance tool used to determine the thicknesses and depths of geological layers and their respective soil or rock types. The method relies on the fact that soil and rock have distinctive electrical resistivity contrasts between bedding layers. The resistivity of soils and rocks depends on three factors (Telford, et al., 1976): 1) the amount of open space between particles (the porosity), 2) the degree of interconnection among these open spaces (the effective porosity), and 3) the amount and conductivity of the water contained in the interconnected spaces (the pore water content and pore water conductivity). In general, electrical resistivity is inversely related to porosity, pore water content, and pore water conductivity (salinity) -- resistivity decreases as these quantities increase. The method is most useful where there is a large contrast in porosity or pore water conductivity between layers (such as between soil and bedrock), between soils above and below the water table, or between sands and clays. The method is much less useful in areas with thick clay layers or in areas with layers having very high or very low resistivity -- these types of layers can mask the lower layers. The pore water conductivity in the soil or rock is the single most important factor determining resistivity.

Electrical resistivity data are obtained by applying a low-frequency or DC current between positive and negative steel electrodes hammered into the ground along a linear transect. For this investigation, four-electrode arrays were used: one pair for introducing the current into the ground (the "current electrodes"), and the other pair for measuring the potential (voltage) associated with the current (the "potential electrodes"). The current flows through the ground from the two current electrodes, and the resulting voltage is measured at the two potential electrodes. The electrode spacing is directly related to the depth of current penetration. The spacing of the electrodes along the transect is increased systematically to obtain a series of measurements of electrical resistivity at increasing depth. For a more complete description of the electrical resistivity method, refer to Dobrin (1976), Telford, et al. (1976), or Benson, et al. (1985).

The electrical resistivity survey was conducted using an ABEM Terrameter SAS-300 transmitter/receiver with appropriate steel stakes and cabling. A modified Schlumberger stake configuration was used (Telford, et al., 1976, p. 656-657). In this Schlumberger method, the current electrodes are spaced much farther apart than the potential electrodes, and the stake positions are moved out from a common center point. The survey used ten electrical resistivity transects to provide both a continuous profile of subsurface geological units and, when possible, the depths to the water table and the underlying bedrock. Six transects were performed in October 1989; the other four transects were run in July 1990. Two electrical resistivity transects were run in the Production Area, five were run in the Warwick Area, and three were run in the Waste Water Treatment Area. Figure 2-1 shows the location of each transect. Note that two transects (6a and 6b) in the western part of the Warwick Area were on the same line.

Measurements were taken at up to 24 electrode spacings along each electrical resistivity transect. The maximum spacing of current electrodes allowed by the cabling is 480 feet, yielding a maximum depth of penetration of approximately 120 feet. However, eight electrical resistivity transects in this survey (1, 2, 4, 5, 6a, 6b, 9, and 11) were shorter than the maximum length of the cable.

Analyses

The field data were entered into the KECKRES computer program (Keck Consulting Services, Inc., undated). The Keck correction (Keck, 1981) was used to correct the apparent resistivities obtained. This correction eliminates surface effects and accentuates deeper observations. Both the apparent resistivity and the corrected resistivity were plotted against depth. The corrected resistivity plots were interpreted in terms of probable soil and rock types. Geological data from borehole sampling were compared to the resistivity results to aid in data interpretation. (These comparisons are discussed in Section 3.0.)

2.3.3 Ground-Penetrating Radar Survey

The ground-penetrating radar survey used the following methods and procedures.

Method

Ground-penetrating radar (GPR) is a reconnaissance tool for locating natural and man-made subsurface features that may impede the flow of ground water, and for avoiding objects while drilling. The method relies on the fact that soil and rock layers (as well as other subsurface features that could affect ground water flow or contaminant migration) reflect radar from surfaces between layers having a high conductivity contrast. It is most useful in areas containing resistive materials (such as dry rocks, or clean sands that have been saturated with fresh water). It is much less useful in areas having conductive materials (such as clay or rocks with conductive pore fluid). GPR data are obtained by irradiating the ground with wide-band, very-high-frequency, short-duration radar pulses (on the order of nanoseconds) from a broad bandwidth transmitting antenna placed close to, and electromagnetically coupled with, the ground surface. The transmitting antenna is towed along the ground at a constant speed, and a 0.5 milliwatt signal pulse is radiated downward at a repetition rate of 50 kilohertz (Khz). The reflected signal is picked up by a receiving antenna. The reflected signals are amplified and processed, and subsequently printed on a high-speed scanning graphic recorder to permit observation and interpretation of the subsurface in real time. Travel times of the reflected pulses can be converted to depths from which the pulses were reflected. By towing the transmitting antenna over the traverses (lines) of a rectangular grid, the size and orientation of the reflective subsurface features can be estimated.

This survey used a Geophysical Survey Systems SIR System 8 unit, which produced a continuous graphical record of the subsurface along each traverse on a high-speed graphic line scan recorder. The system was set to record reflections from travel times corresponding to depths of 0 to 10 feet. The transmitting antenna was towed behind a pickup truck when possible, but was pulled by hand in areas where the vehicle would have been unable to turn around. The GPR survey used three grids with lines running north-south and east-west. The Production Area was surveyed in a ten-foot grid. The Warwick and Waste Water Treatment areas were surveyed in twenty-foot grids. The grid survey work was performed by a licensed (subcontract) surveyor. Each of the three grids was tied into the Rhode Island survey grid by at least one point. Figures 2-2, 2-3, and 2-4 show the grids, starting points, and directions of traversal for the GPR surveys in the Production, Warwick, and Waste Water Treatment areas, respectively.

<u>Analyses</u>

The GPR data were interpreted and subsurface anomalies were identified and plotted on a map of each study area in two dimensions (depth and width of feature) for each transect. The third dimension (length of feature) was added by concatenating the two-dimensional information across transects. The GPR data were then compared to the facility's utility plans. Reflection patterns consistent with pipes, conduits, tanks, piles, and wells were identified, when possible, on a map of each study area.

2.4 RESULTS OBTAINED

A subsurface model was produced combining information from the geological investigation of the site (Section 3.0) and all the information available from the seismic refraction, electrical resistivity, and GPR surveys. The results from all three surveys are described here. Complete, detailed analyses for each of the surveys are presented in Appendix B.

2.4.1 Production Area

Results of the three seismic refraction lines run in the Production Area (Figures 2-5 through 2-7) indicate that bedrock probably lies at a depth averaging 60 feet. Two of the three seismic lines (lines 1 and 8) did not differentiate bedrock, however. The bedrock may be overlain by a dense glacial till of varying thickness. A thick alluvium consisting of discontinuous and interfingering sands, clays, gravels, and silts overlies the till/bedrock.

Results of the two electrical resistivity soundings run in the Production Area (Figures 2-8 and 2-9) generally agree with the results of the seismic refraction survey. The data indicate that interbedded and discontinuous sands, clays, silts, and gravels extend from the surface down to a dense glacial till of varying thickness (up to, and in excess of 15 feet thick) that begins at depths as shallow as 30 feet and extends as deep as 60 feet. Bedrock appears to lie at depths of 50 to 60 feet.

Results of the ground-penetrating radar survey (Figure 2-10) indicate that individual buried utilities could not be discriminated in this area. The numerous pipe-like anomalies that were located do not match the pipe locations shown on the utility maps. Slab-like anomalies generally agreed with foundations shown on the utility maps.

2.4.2 Warwick Area

Results of the five seismic refraction lines run in the Warwick Area (Figures 2-11 through 2-15) indicate that bedrock lies at an average depth of 55 to 60 feet. Bedrock may be overlain by a dense glacial till of varying thickness. Alluvium consisting of interbedded and discontinuous sands, clays, silts, and gravels extends from the ground surface to the till.

Results of the five electrical resistivity soundings run in the Warwick Area (Figures 2-16 through 2-20) generally agree with the results of the seismic refraction survey. Bedrock appears to lie at depths of about 60 feet, and is overlain by a dense glacial till of varying thickness (up to about 30 feet thick). Interfingering and discontinuous alluvium consisting of sands, silts, clays, and gravels extends from the surface to the till.

Results of the ground-penetrating radar survey (Figure 2-21) indicate that individual buried utilities could not be discriminated in this area. The pipe-like anomalies that were located do not match the pipe locations shown on the utility maps. Slab-like anomalies generally agreed with foundations shown on the utility maps.

2.4.3 Waste Water Treatment Area

Results of the three seismic refraction lines run in the Waste Water Treatment Area (Figures 2-22 through 2-24) indicate that bedrock (layer 3) lies at depths of about 45 to 60 feet. Results generally indicate that a dense glacial till of varying thickness lies at depths ranging from about 25 to 50 feet. Alluvium overlies the till and consists of interbedded and discontinuous sands, clays, and gravels.

Results of the three electrical resistivity soundings run in the Waste Water Treatment Area (Figures 2-25 through 2-27) generally agree with the results of the seismic refraction survey, and indicate bedrock lying at depths of about 45 to 60 feet. Glacial till of varying thickness (10 to 30 feet thick) overlies the bedrock. Discontinuous and interfingering alluvium consisting of sands, clayey silts, silty clays, and gravels overlies the till.

Results of the ground-penetrating radar survey (Figure 2-28) indicate that individual buried utilities could not be discriminated in this area. The pipe-like anomalies that were located do not match the pipe locations shown on the utility maps. Slab-like anomalies generally agreed with foundations shown on the utility maps.

2.5 DISCUSSION

This section compares the results obtained from the seismic refraction and electrical resistivity surveys in the Production, Warwick, and Waste Water Treatment areas. Since the ground-penetrating radar survey only extended to a depth of 10 feet and no correlations could be made with mapped utilities, it will not be discussed further.

2.5.1 Production Area

The seismic refraction and electrical resistivity data from the Production Area indicate the presence of glacial till of variable composition and thickness overlying bedrock. Interbedded sands, silts, gravels, and clays overlie the till with no apparent consistent horizontal layering. The data indicate that till is encountered at depths of 30 to 60 feet (Figures 2-8 and 2-9), with varying thickness. Bedrock is encountered below depths of 50 to 60 feet and may be weathered, jointed, or saturated with brackish water, based on the seismic velocities and electrical resistivities observed (see Appendix C). The dip of the till/bedrock surface (inferred from seismic layer 3 on Figure 2-7) is not considered realistic and is likely a function of possible reflection of the shot energy at the bulkhead.

2.5.2 Warwick Area

The data indicate that the upper 30 feet of soils are interbedded, laterally discontinuous sands, silts, and clays. The electrical resistivity data indicate the presence of till in varying thickness and composition. Weathered and jointed bedrock, or bedrock saturated with brackish water, is encountered at depths of about 50 to 60 feet. The dips of till/bedrock surfaces (inferred from seismic layer 3 on Figures 2-11 through 2-14) may not be realistic; they are more likely a function of horizontal velocity variations in the overburden along each survey line.

The electrical resistivity data for line 10 (Figure 2-20) indicate a thick sequence of interbedded soils to about 60 feet. The uniform resistivities below 60 feet may indicate bedrock. The seismic data (Figure 2-15) show anomalously shallow depth to bedrock. This inconsistency may be due either to buried obstructions or to poor seating of the geophones along the line. The results of the electrical resistivity survey along line 10 are preferred to those of the seismic refraction survey.

2.5.3 Waste Water Treatment Area

The electrical resistivity and seismic refraction data from the Waste Water Treatment Area are generally consistent with the geophysical survey data from the other two study areas. The upper 30 feet of overburden are characterized by interbedded, discontinuous sands, silts, and clays. Till is encountered between depths of about 30 to 50 feet, with the top of bedrock ranging from about 45 to 60 feet. Low resistivities in the bedrock may indicate saturation with brackish water.

Lines 2W and 3 are roughly parallel to one another (as shown in Figure 2-1) and are very similar in trend with lines 5 and 6 (in the Warwick Area). Line 9 is perpendicular to lines 2 and 3 and is consistent in the upper 30 feet of overburden. The till and top of rock along line 9 are not as clearly defined, but appear to be present at depths similar to lines 2 and 3.

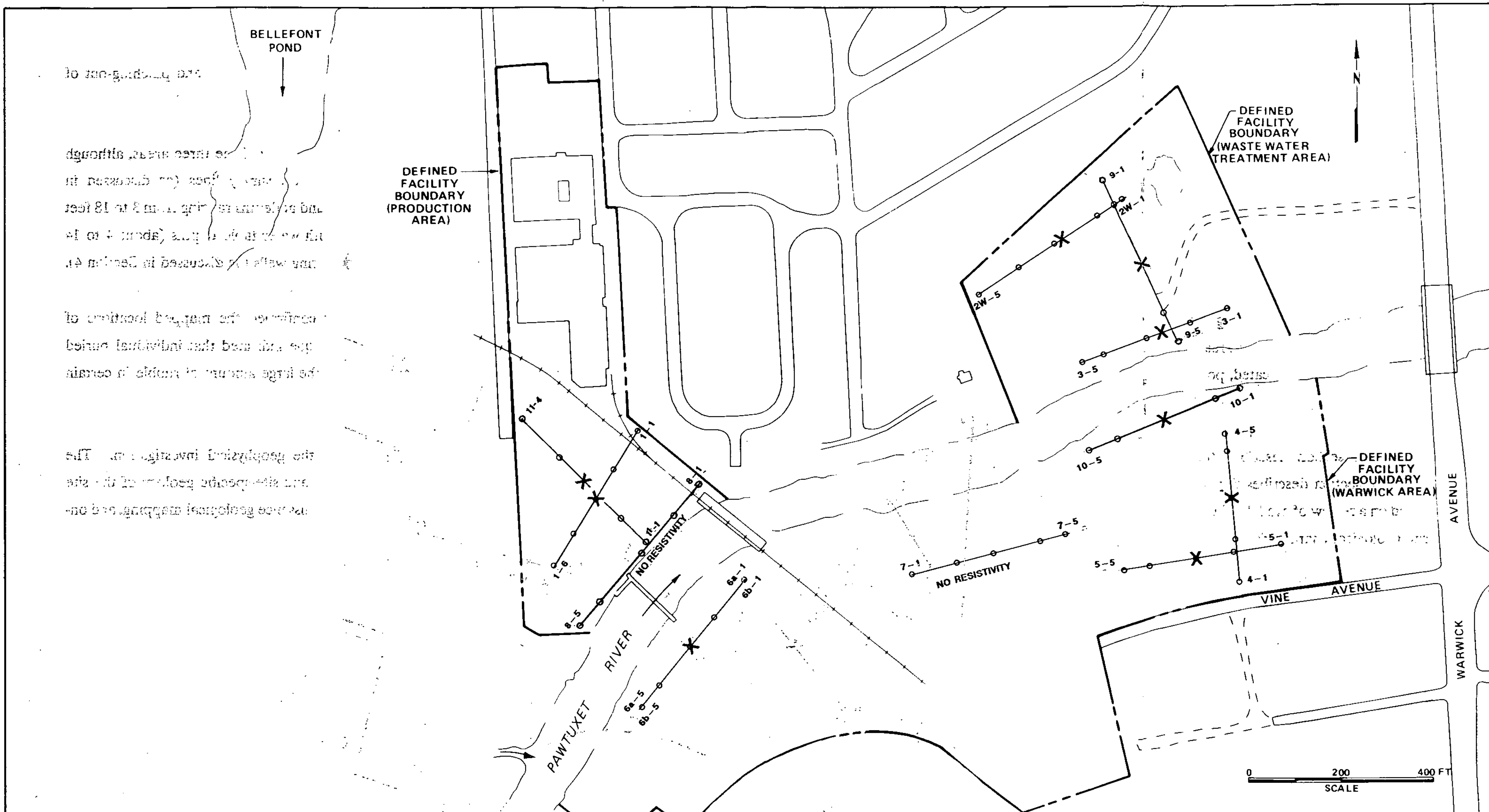
2.6 SUMMARY

An overview of the results of the three geophysical survey techniques was presented here. A more detailed analysis of each survey line is presented in Appendix B. The seismic refraction and electrical resistivity survey results in the three study areas were of varying usefulness for inferring the depth to bedrock and types of overburden present. Neither the seismic refraction survey nor the electrical resistivity survey analyzed alone, permitted a confident interpretation of the depth to bedrock along every survey line. However, used together, and in conjunction with the data obtained from the boring logs, these survey data permitted constructing a reasonable model of the site stratigraphy. Bedrock appears to vary in depth across the site from as little as 45 feet to as much as 60 feet, and may be saturated with brackish water based on the low resistivities observed. The overburden, consisting of sands, clays, silts, gravels, and till, appears to vary widely both in depth and in areal extent over the three study areas; lateral interfingering and pinching-out of these deposits would not be surprising.

Perched water tables were not identified in any of the three areas, although the normal water table was inferred along most survey lines (as discussed in Appendix B). The inferred water table was found at depths ranging from 3 to 18 feet over the site, which is generally consistent with water table depths (about 4 to 14 feet) reported for the piezometers and monitoring wells (as discussed in Section 4).

The ground-penetrating radar survey confirmed the mapped locations of former foundation and slab areas; this technique indicated that individual buried utilities could not be located, possibly due to the large amount of rubble in certain areas.

This section described the results of the geophysical investigation. The following section describes the regional, local, and site-specific geology of the site based on a review of available literature, reconnaissance geological mapping, and on-site geological characterization activities.



LEGEND:

LOCATION OF SEISMIC LINES AND RESISTIVITY SOUNDINGS PERFORMED BY WOODWARD – CLYDE CONSULTANTS IN OCTOBER 1989 AND JULY 1990. SEISMIC SHOT POINT-SHOWN AS OPEN CIRCLES; X REFER TO THE RESISTIVITY MIDPOINT.

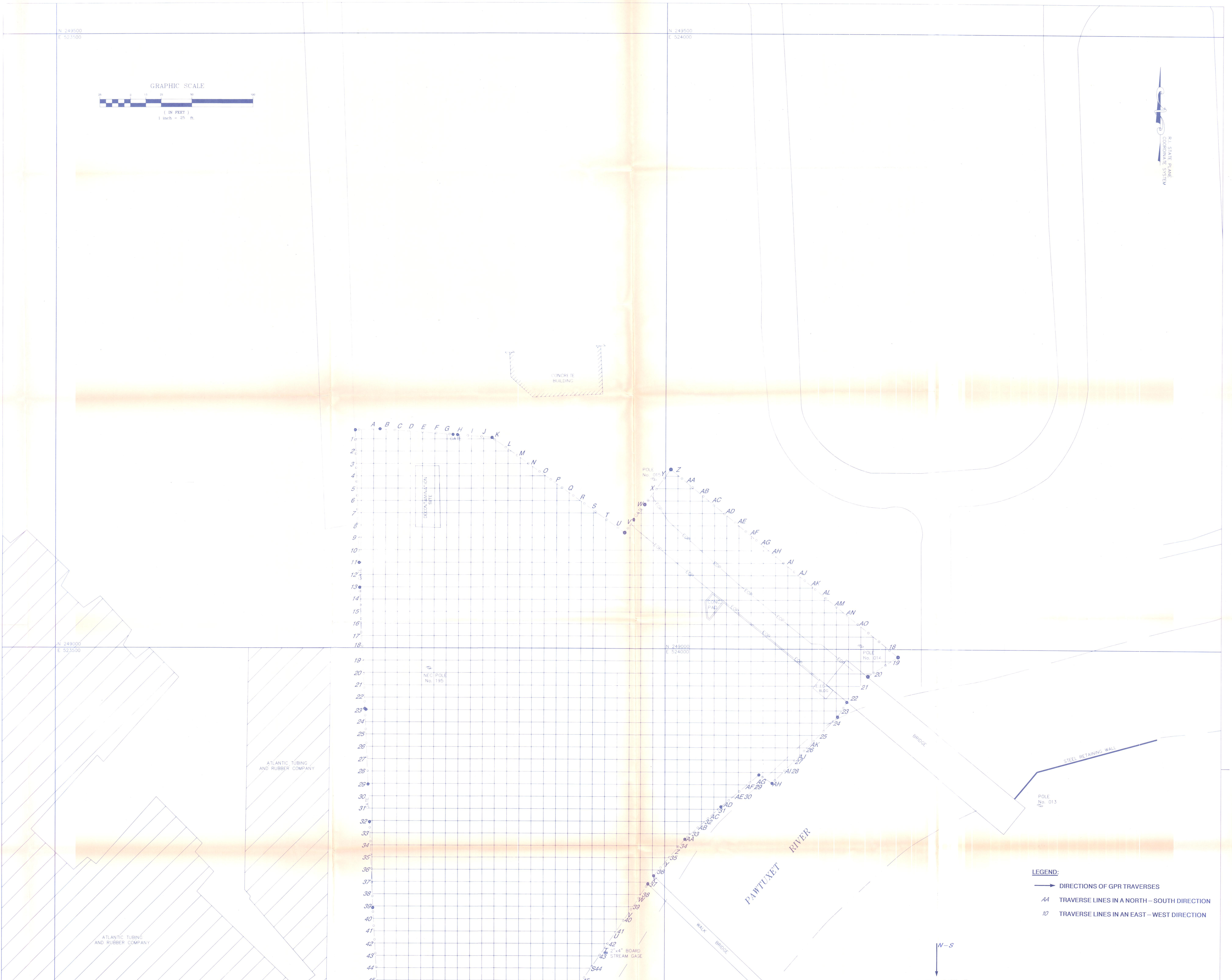
BASE MAP SOURCE:

GEOD CORPORATION OF NEWFOUNDLAND, NEW JERSEY. MAPPED BY PHOTOGRAMMETRIC METHODS FROM AERIAL PHOTOGRAPHS. DATE FLOWN: 2 APRIL 1989.

LOCATION OF SEISMIC LINES AND RESISTIVITY SOUNDINGS
CIBA – GEIGY FACILITY
CRANSTON, RHODE ISLAND

WOODWARD – CLYDE CONSULTANTS
CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS
WAYNE, NEW JERSEY

DR. BY:	KF	SCALE:	1:2400	PROJ. NO.:	87X4660
CK'D. BY:	JDA	DATE:	18 SEPT 1990	FIG. NO.:	2-1



GROUND – PENETRATING RADAR GRID USED IN THE PRODUCTION AREA
CIBA – GEIGY FACILITY
CRANSTON, RHODE ISLAND

WOODWARD-CLYDE CONSULTANTS
CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS
WAYNE, NEW JERSEY

DR. BY: KF	SCALE: AS SHOWN	PROJ. NO.: 87X4660
CK'D. BY: JDA	DATE: 28 SEPT 1990	FIG. NO.: 2-2

LEGEND:

DIRECTIONS OF GPR TRAVERSES

AA TRAVERSE LINES IN A NORTH – SOUTH DIRECTION

10 TRAVERSE LINES IN AN EAST – WEST DIRECTION

GROUND – PENETRATING RADAR GRID USED IN THE WARWICK AREA
CIBA – GEIGY FACILITY
CRANSTON, RHODE ISLAND

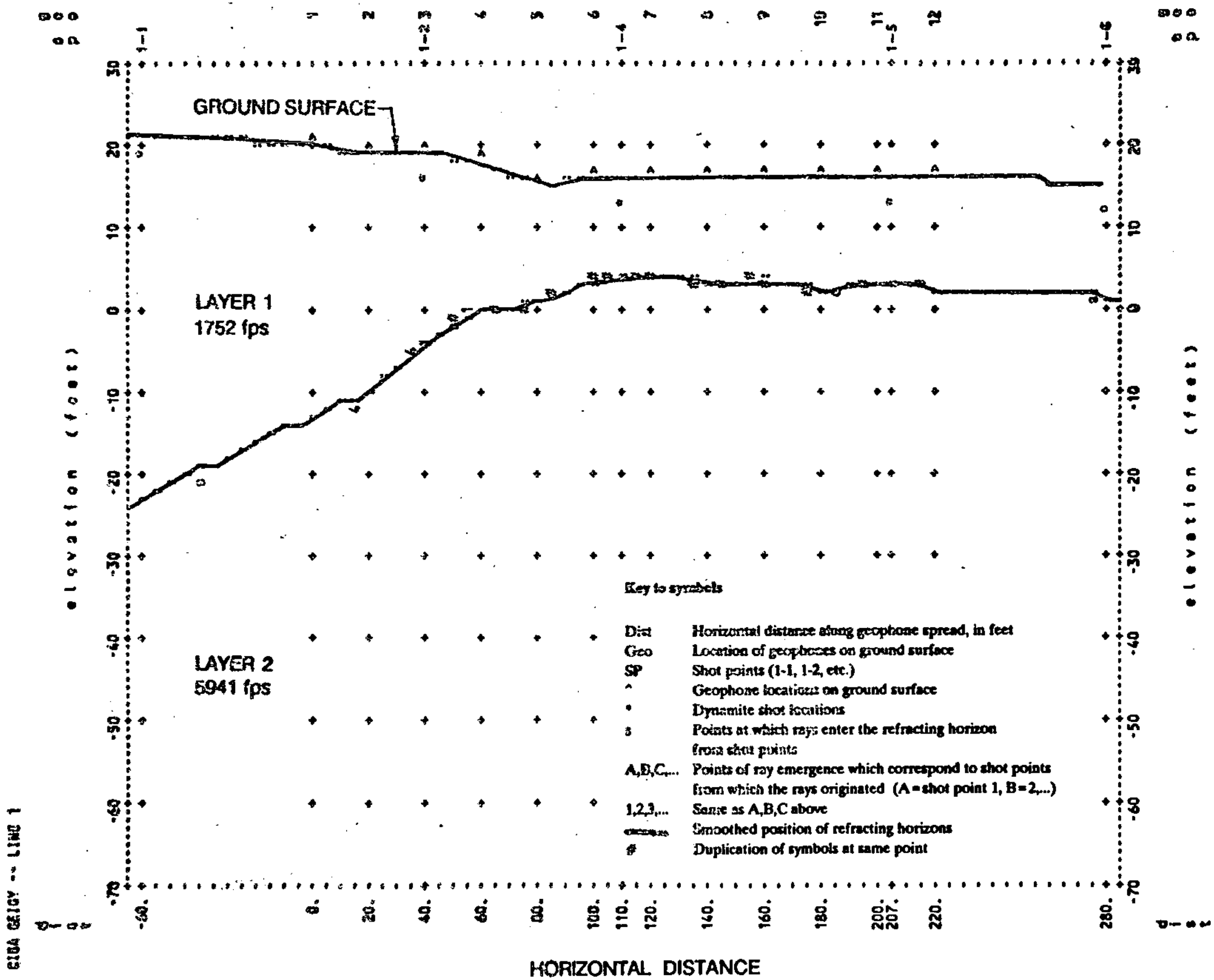
WOODWARD-CLYDE CONSULTANTS
CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS
WAYNE, NEW JERSEY

DR. BY:	KF	SCALE:	AS SHOWN	PROJ. NO.:	87X4660
CK'D. BY:	JDA	DATE:	28 SEPT 1990	FIG. NO.:	2–3

GROUND – PENETRATING RADAR GRID USED IN THE WASTE WATER TREATMENT AREA
CIBA – GEIGY FACILITY
CRANSTON, RHODE ISLAND

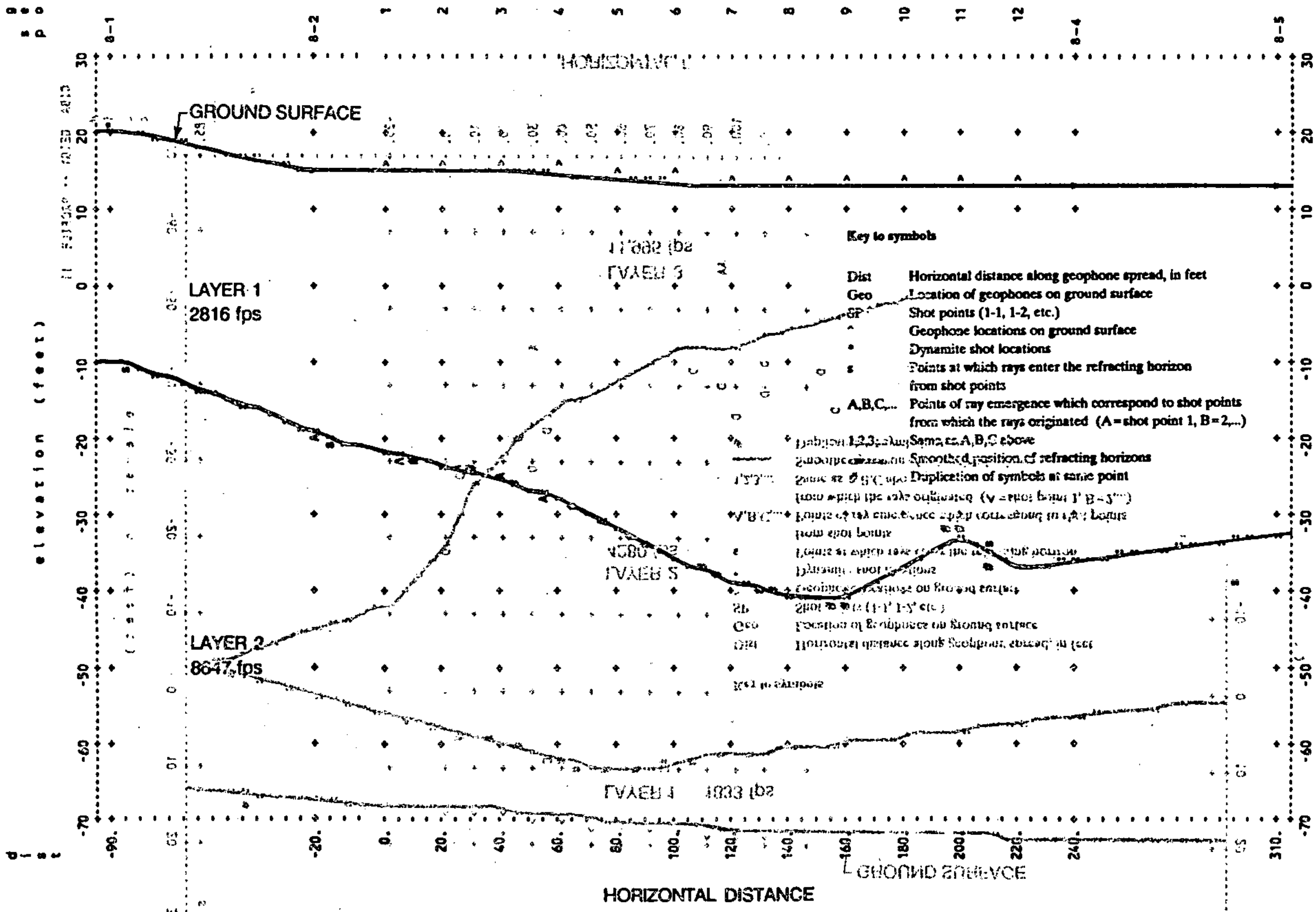
WOODWARD-CLYDE CONSULTANTS
CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS
WAYNE, NEW JERSEY

DR. BY:	KF	SCALE:	AS SHOWN	PROJ. NO.:	87X4660
CK'D. BY:	JDA	DATE:	28 SEPT 1990	FIG. NO.:	2–4



PRODUCTION AREA – SEISMIC REFRACTION LINE 1 CROSS – SECTION

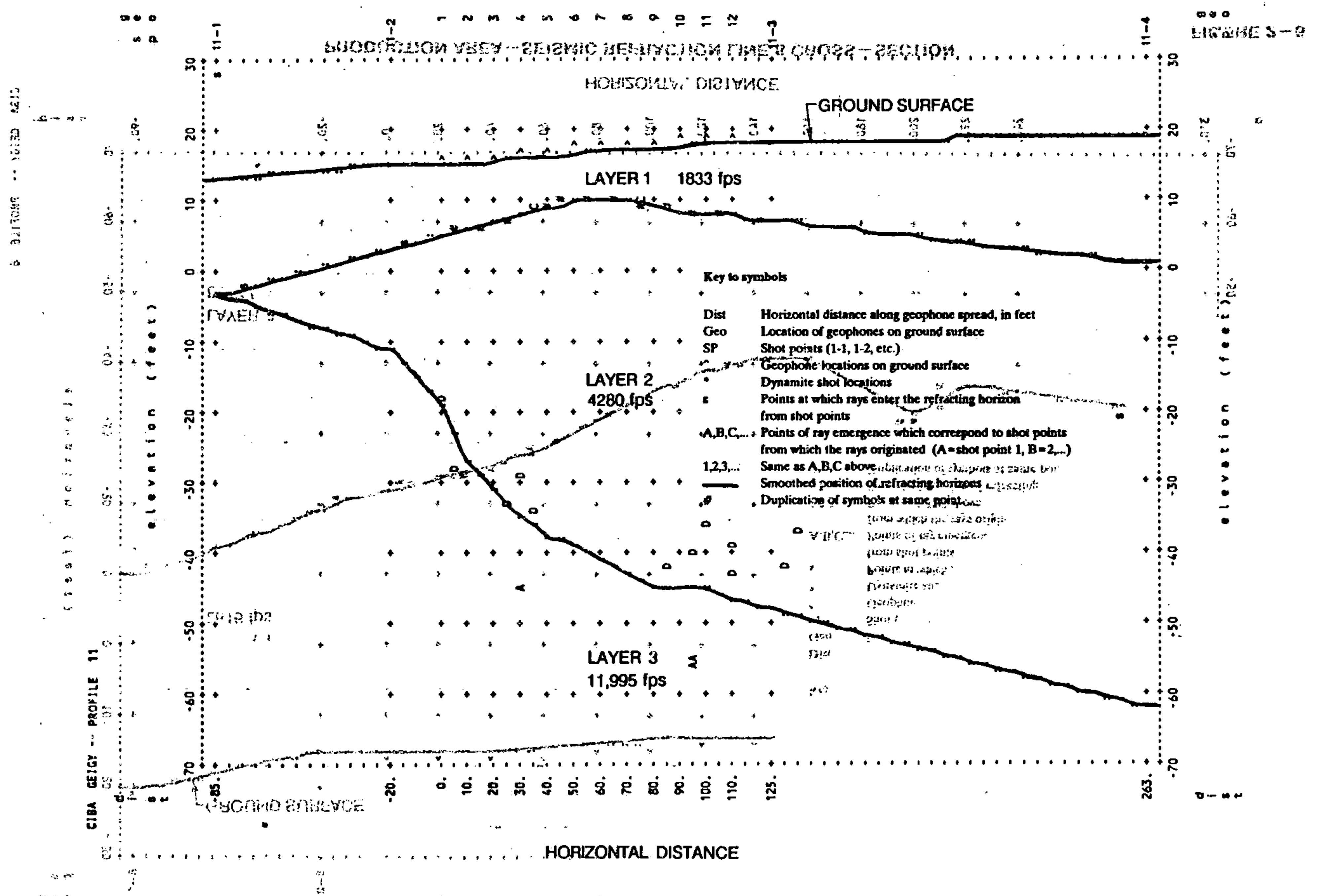
FIGURE 2 – 5



PRODUCTION AREA – SEISMIC REFRACTION LINE 8 CROSS – SECTION

FIGURE 2–6


N 249500
E 523500
N 249500
E 524000
GRAPHIC SCALE
(IN FEET)
1 inch = 25 ft.
R.I. STATE PLANE
COORDINATE SYSTEM
CONCRETE
BUILDING
(NOT GPR
SURVEYED)
DECONTAMINATION
SITE
KNOWN
METALLIC
OBJECTS
POLE
No. 015
CONC
PAD
(NOT
GPR
SURVEYED)
N 249000
E 523500
N 249000
E 524000
POLE
No. 014
BRIDGE
STEEL RETAINING WALL
POLE
No. 013
ATLANTIC TUBING
AND RUBBER COMPANY
ATLANTIC TUBING
AND RUBBER COMPANY
PAWTUXET RIVER
WALK BRIDGE
2"x4" BOARD
STREAM GAGE
LEGEND:
INITIAL ANOMALIES
LINEAR ANOMALIES (DASHED
WHERE INFERRED)
POSSIBLE FOUNDATION/SLABS
WELL
GROUND – PENETRATING RADAR ANOMALIES DETECTED
PRODUCTION AREA
CIBA – GEIGY FACILITY
CRANSTON, RHODE ISLAND
WOODWARD-CLYDE CONSULTANTS
CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS
WAYNE, NEW JERSEY
DR. BY: KF
SCALE: AS SHOWN
PROJ. NO.: 87X4660
CK'D. BY: JDA
DATE: 28 SEPT 1990
FIG. NO.: 2–10



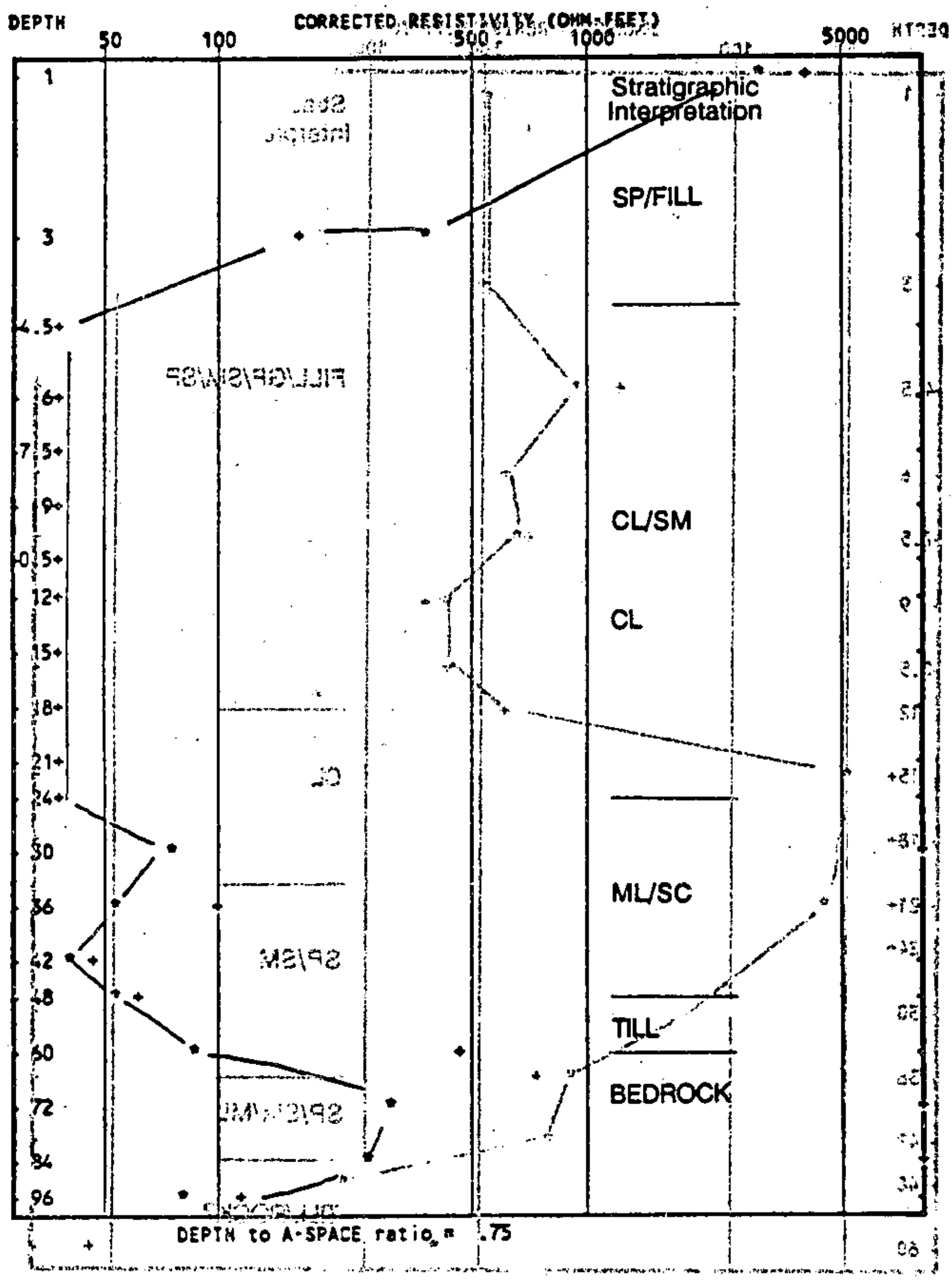
PRODUCTION AREA—SEISMIC REFRACTION LINE 11 CROSS—SECTION

FIGURE 2—7

FILE LABEL: cibe STATION: Line 1

CORRECTED RESISTIVITY (OHM-FEET)

A-SPACE	DEPTH	RESIS	FULL+	PARTIAL
2	0-2	X218.700	3561	2748
4	2-4	39.830	158	342
6	3-6	8.560	35	1
8	4-8	3.140	24	0
10	5-10	1.700	10	0
12	6-12	1.280	15	20
14	7-14	0.977	12	23
16	8-16	0.645	12	27
20	10-20	0.075	1	0
24	12-24	0.116	1	0
28	14-28	0.146	4	5
32	16-32	0.149	9	15
40	20-40	0.080	8028	71
48	24-48	0.091	91	47
56	28-56	0.088	42	37
64	32-64	0.093	55	47
80	40-80	0.072	432	79
96	48-96	0.102	60284	268
112	56-112	0.094	22088	235
128	64-128	0.065	104	75



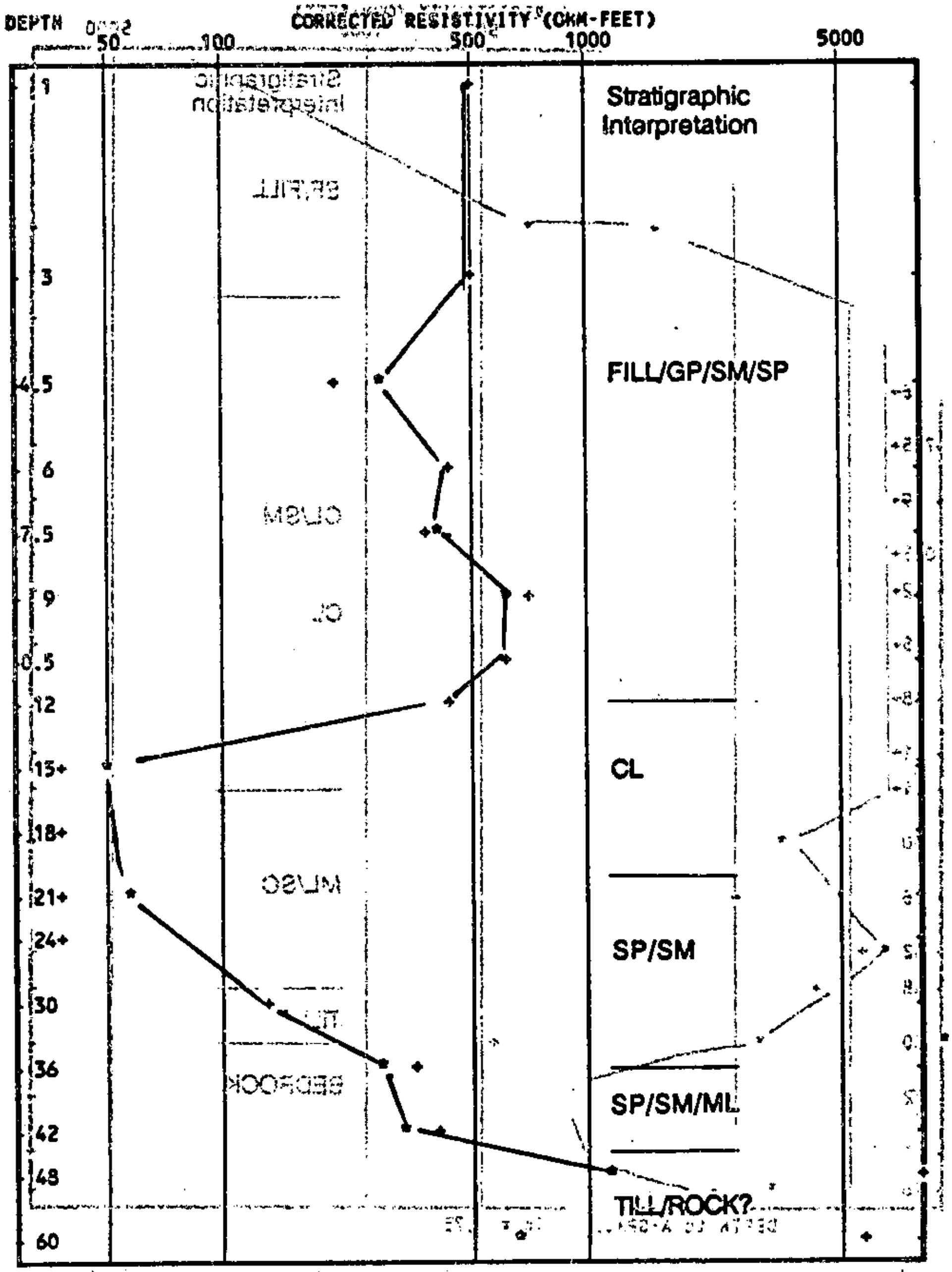
PRODUCTION AREA – ELECTRICAL RESISTIVITY SOUNDING 1 CROSS – SECTION

FIGURE 2–8

FILE LABEL: ciba STATION: CIBA 11

CORRECTED RESISTIVITY (OHM-FEET)

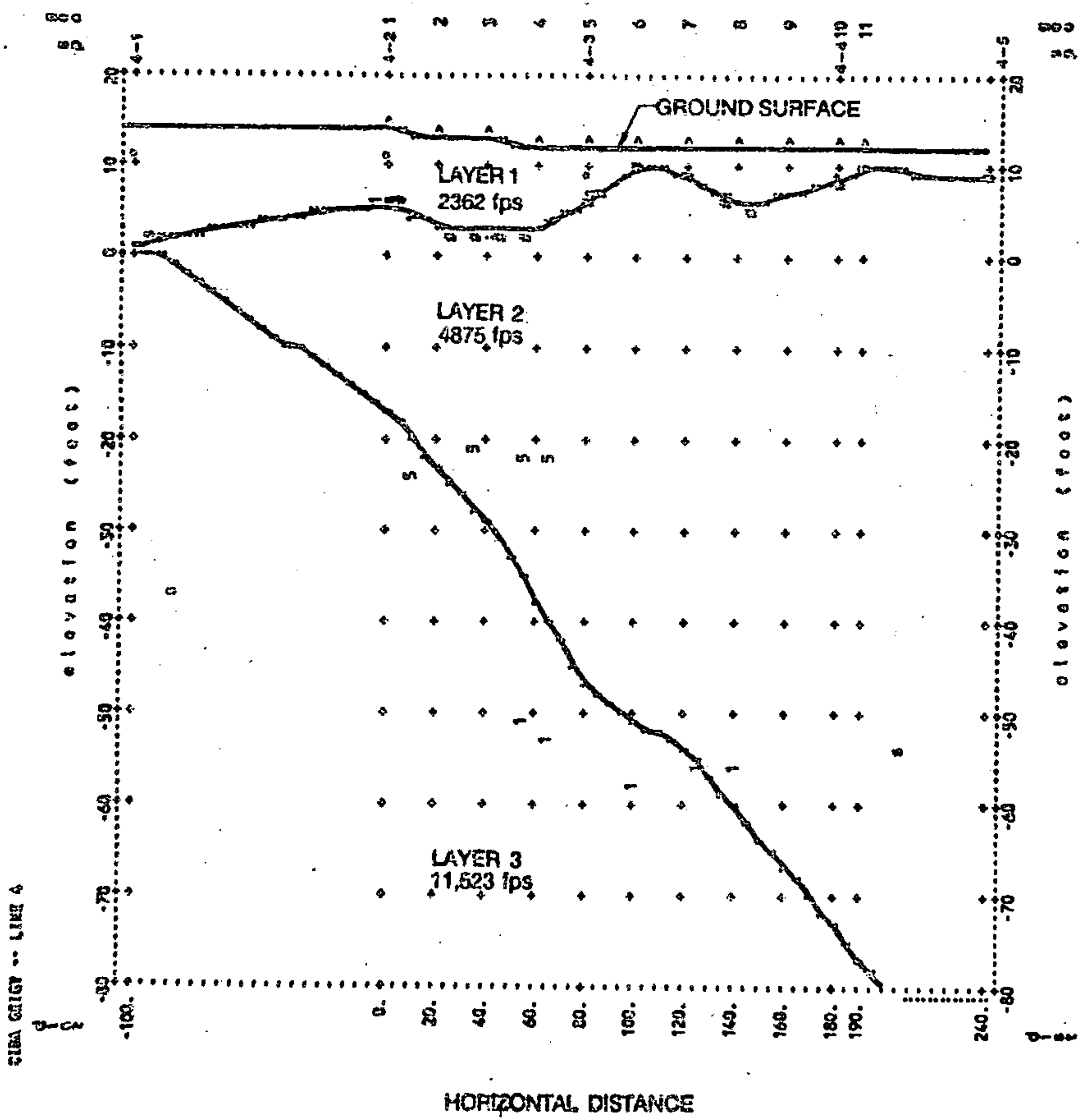
A-SPACE	DEPTH	RESIS	FULL	PARTIAL
2	0-2	36.190	455	455
4	2-4	18.140	456	457
6	3-6	11.310	193	255
8	4-8	8.540	396	406
10	5-10	6.520	343	363
12	6-12	6.610	640	582
14	7-14	5.590	577	544
16	8-16	4.150	402	406
20	10-20	1.150	21	46
24	12-24	0.870	15	14
28	14-28	0.960	28	51
32	16-32	0.590	16	20
40	20-40	0.540	125	128
48	24-48	0.590	323	246
56	28-56	0.630	368	294
64	32-64	0.650	186708	1053
80	40-80	0.500	5165	588



DEPTH to A-SPACE ratio = .75

PRODUCTION AREA—ELECTRICAL RESISTIVITY SOUNDING 11 CROSS—SECTION

FIGURE 2—9

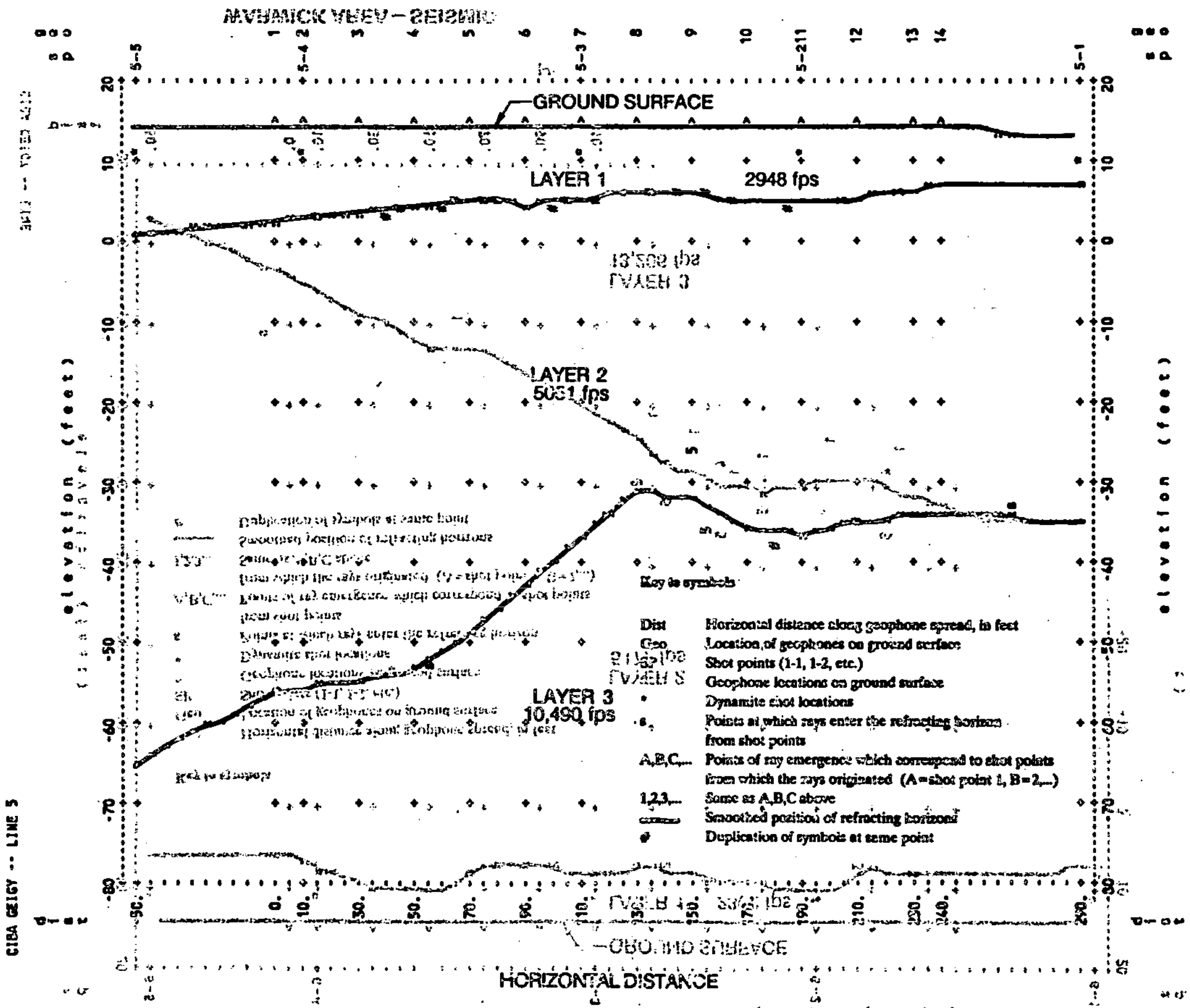


Key to symbols

Dist	Horizontal distance along geophone spread, in feet
Geo	Location of geophones on ground surface
SP	Shot points (1-1, 1-2, etc.)
^	Geophone locations on ground surface
•	Dynamite shot locations
■	Points at which rays enter the refracting horizon from shot points
A,B,C,...	Points of ray emergence which correspond to shot points from which the rays originated (A = shot point 1, B = 2,...)
1,2,3,...	Same as A,B,C above
▬▬	Smoothed position of refracting horizons
#	Duplication of symbols at same point

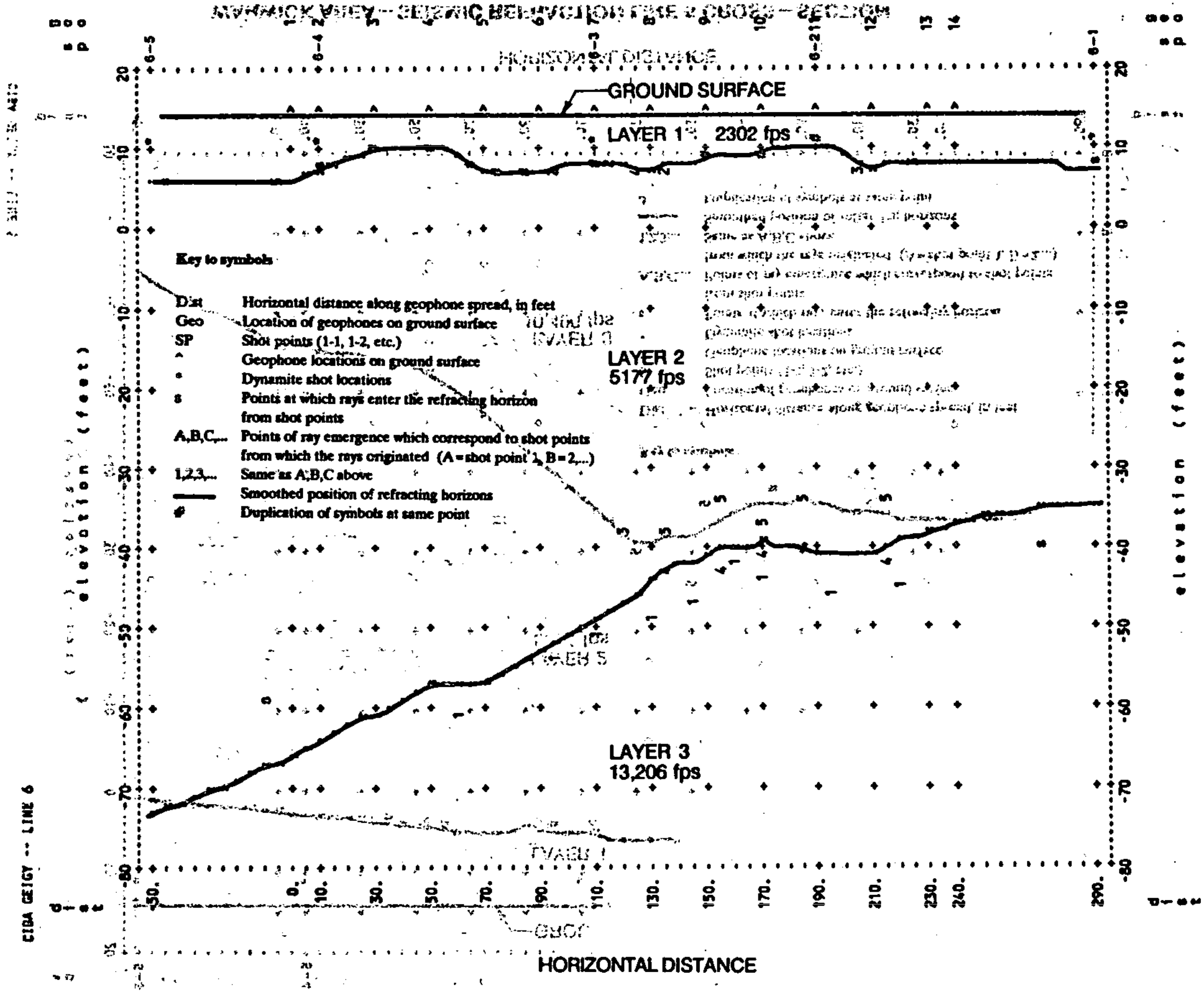
WARWICK AREA — SEISMIC REFRACTION LINE 4 CROSS — SECTION

FIGURE 2 — 11



WARWICK AREA – SEISMIC REFRACTION LINE 5 CROSS-SECTION

FIGURE 2 – 12



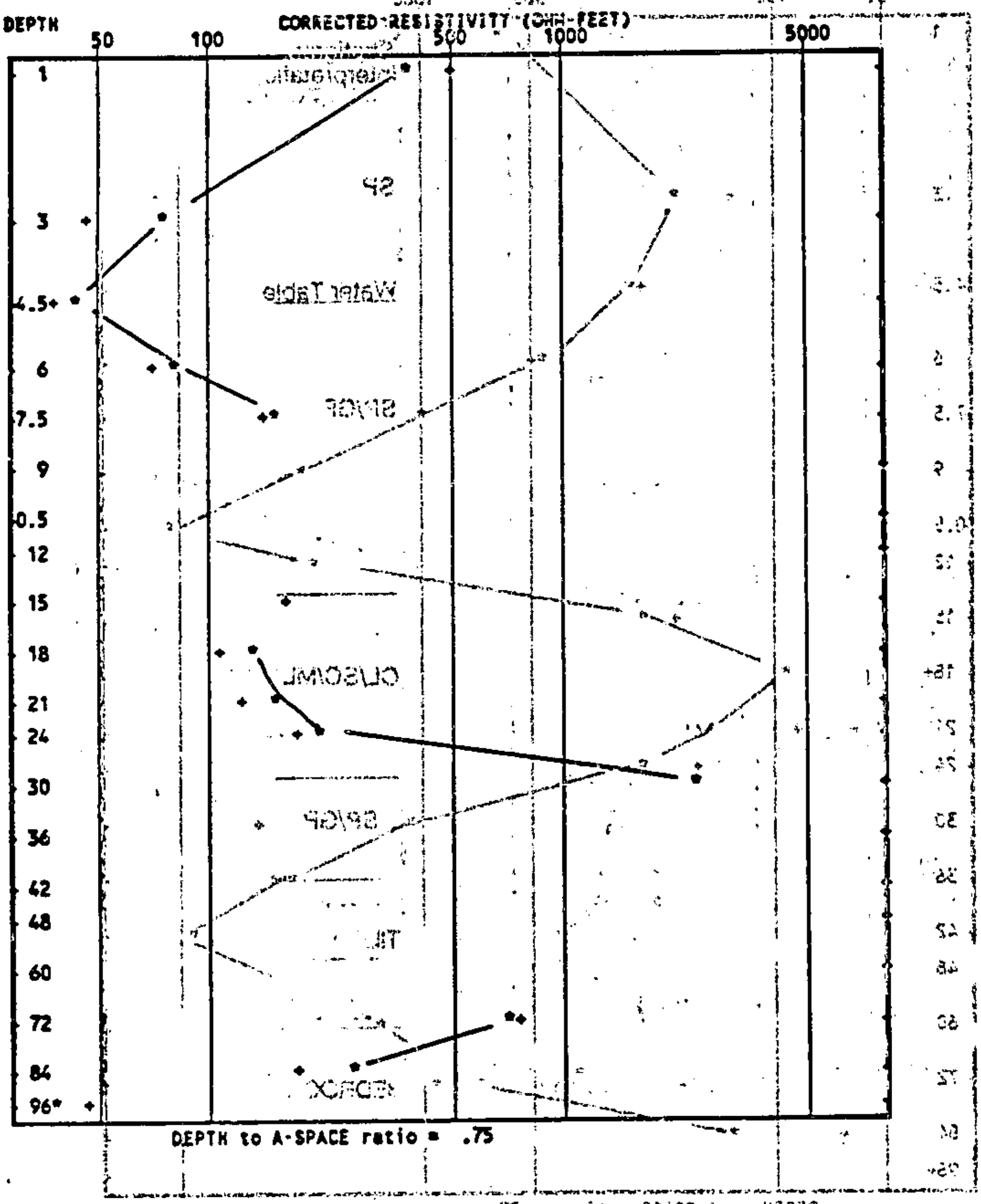
WARWICK AREA – SEISMIC REFRACTION LINE 6 CROSS – SECTION

FIGURE 2 – 13

FILE LABEL: cibe   STATION: Line 6-A

CORRECTED RESISTIVITY (OHM-FEET)

A-SPACE	DEPTH	RESIS	FULL	PARTIAL
2	0-2	26.500	453	333
4	2-4	6.020	43	76
6	3-6	2.170	25	40
8	4-8	2.075	65	[illegible]
10	5-10	2.340	136	16[illegible]
12	6-12	1.450	%231400352	%142152
14	7-14	1.800	%1351355S3920	%4574372
16	8-16	1.750	%4480120872	%1893339
20	10-20	1.180	150	142
24	12-24	1.150	105	122
28	14-28	1.220	110	146
32	16-32	1.300	16[illegible]	190
40	20-40	1.410	1148774	2183
48	24-48	1.760	%219817344	%155943
56	28-56	2.240	%12924478464	%5257909
64	32-64	3.150	%.611684E+07	%[illegible]471E+06
80	40-80	2.000	%915739043	70552
96	48-96	0.978	692	652
112	56-112	0.590	169	234
128	64-128	0.366	41	8



WARWICK AREA – ELECTRICAL RESISTIVITY SOUNDING 6a CROSS – SECTION

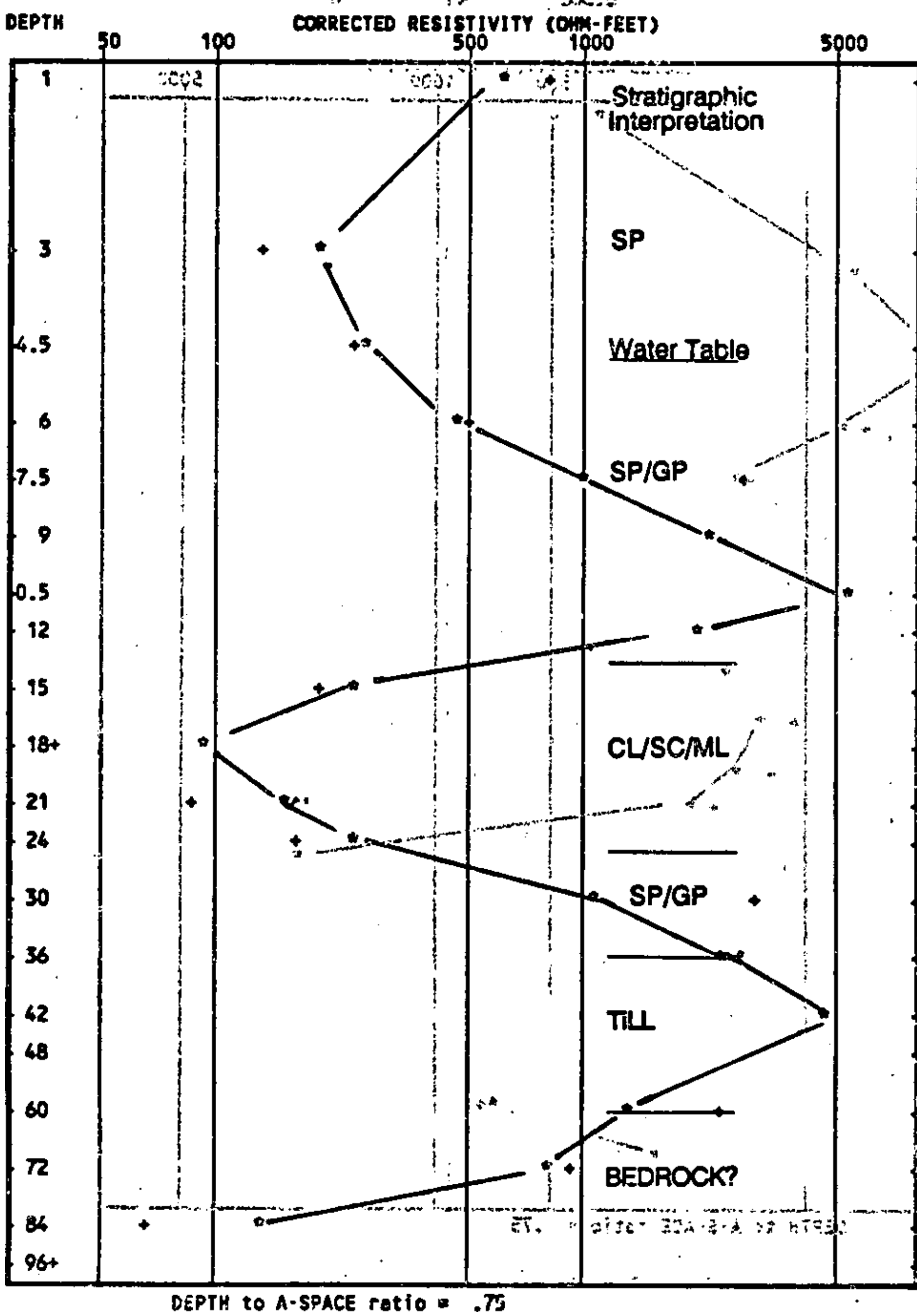
FIGURE 2 – 18

FILE LABEL: ciba

STATION: CIBA 6-B

CORRECTED RESISTIVITY (OHM-FEET)

A-SPACE	DEPTH	RESIS	FULL	PARTIAL
2	0-2	45.440	744	571
4	2-4	12.070	125	173
6	3-6	7.530	219	238
8	4-8	7.090	461	418
10	5-10	7.610	2479	903
12	6-12	7.990	219174	2092
14	7-14	7.990	3094129	4808
16	8-16	6.990	73016	1926
20	10-20	2.490	181	216
24	12-24	1.550	32	89
28	14-28	1.760	79	142
32	16-32	1.860	155	213
40	20-40	2.080	2733	989
48	24-48	1.730	472840	2226
56	28-56	2.070	1749845	4098
64	32-64	3.270	%8924583936	%4044236
80	40-80	1.560	2196	1284
96	48-96	1.050	876	769
112	56-112	0.430	61	128
128	64-128	0.240	27	0



DEPTH to A-SPACE ratio = .75

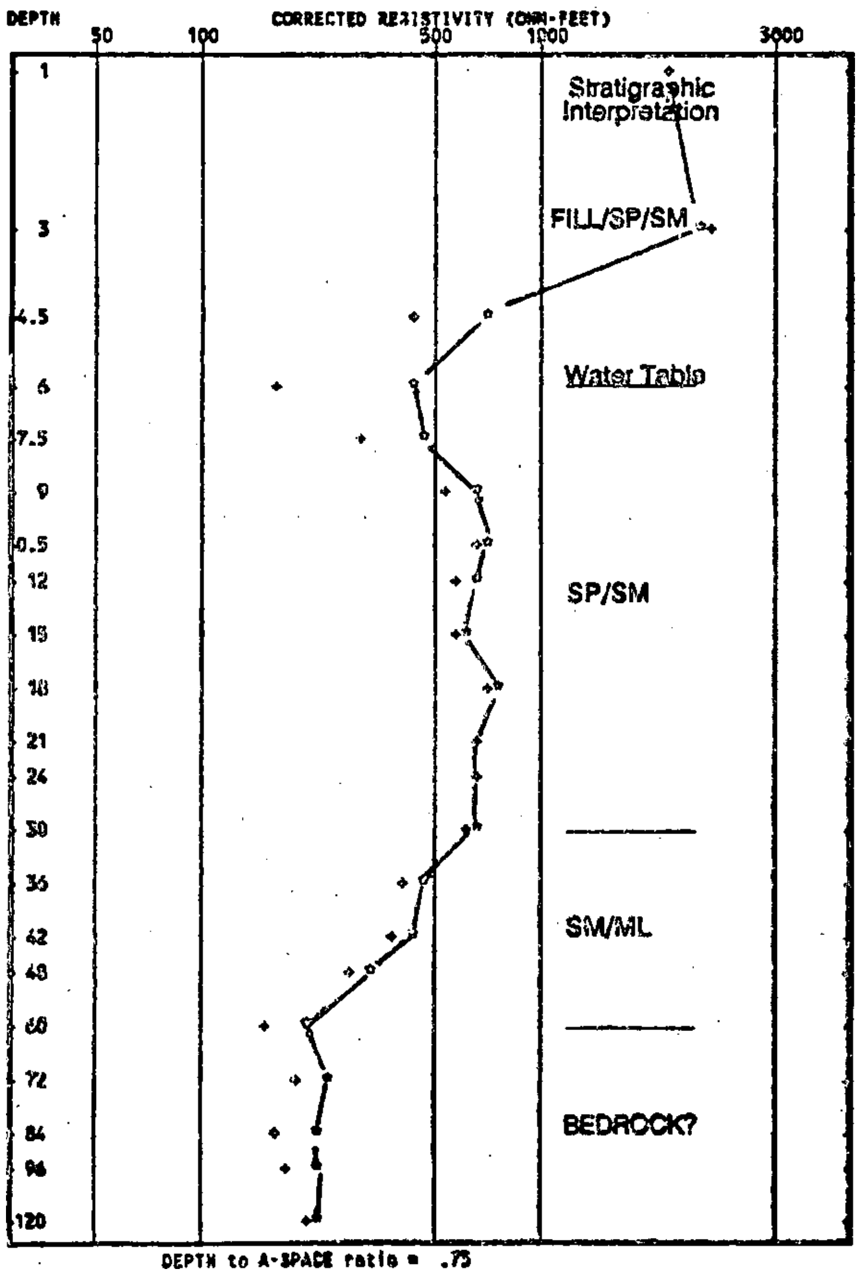
WARWICK AREA – ELECTRICAL RESISTIVITY SOUNDING 6b CROSS – SECTION

FIGURE 2 – 19

FILE LABEL: ciba STATION: CIBA 10

CORRECTED RESISTIVITY (OHM-FEET)

A-SPACE	DEPTH	RESIS	FULL	PARTIAL*
2	0-2	%179.840	2130	2260
4	2-4	%100.550	2992	2819
6	3-6	36.340	394	660
8	4-8	19.770	151	388
10	5-10	14.050	273	437
12	6-12	11.620	484	594
14	7-14	9.660	600	671
16	8-16	7.530	534	597
20	10-20	5.630	527	582
24	12-24	5.080	641	679
28	14-28	4.110	586	626
32	16-32	3.380	590	617
40	20-40	2.570	572	595
48	24-48	1.850	370	424
56	28-56	1.460	331	382
64	32-64	1.100	253	304
80	40-80	0.680	148	194
96	48-96	0.570	182	226
112	56-112	0.440	138	199
128	64-128	0.360	157	200
160	80-160	0.260	123	207



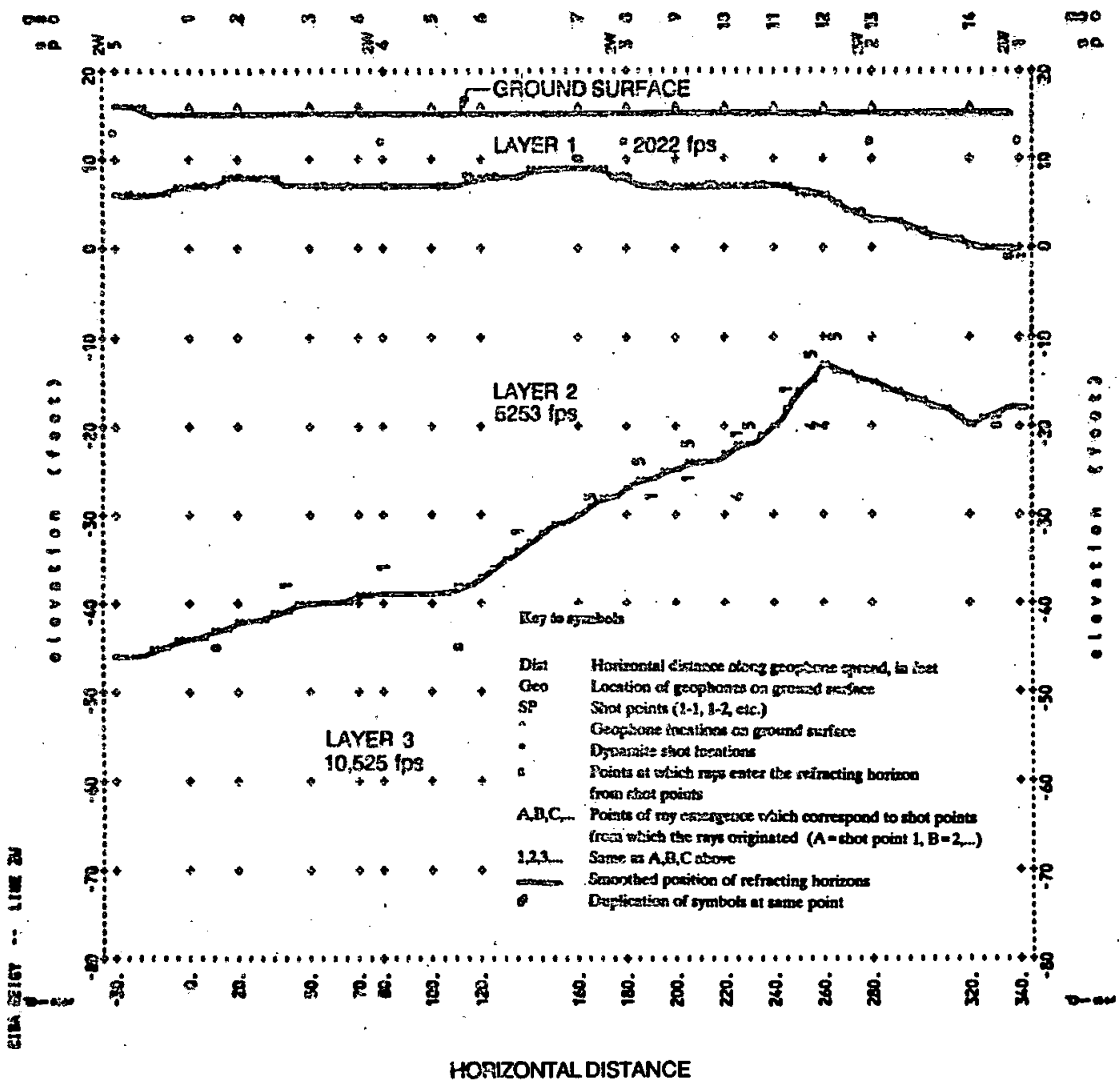
WARWICK AREA – ELECTRICAL RESISTIVITY SOUNDING 10 CROSS – SECTION

FIGURE 2 – 20

GROUND – PENETRATING RADAR ANOMALIES DETECTED
WARWICK AREA
CIBA – GEIGY FACILITY
CRANSTON, RHODE ISLAND

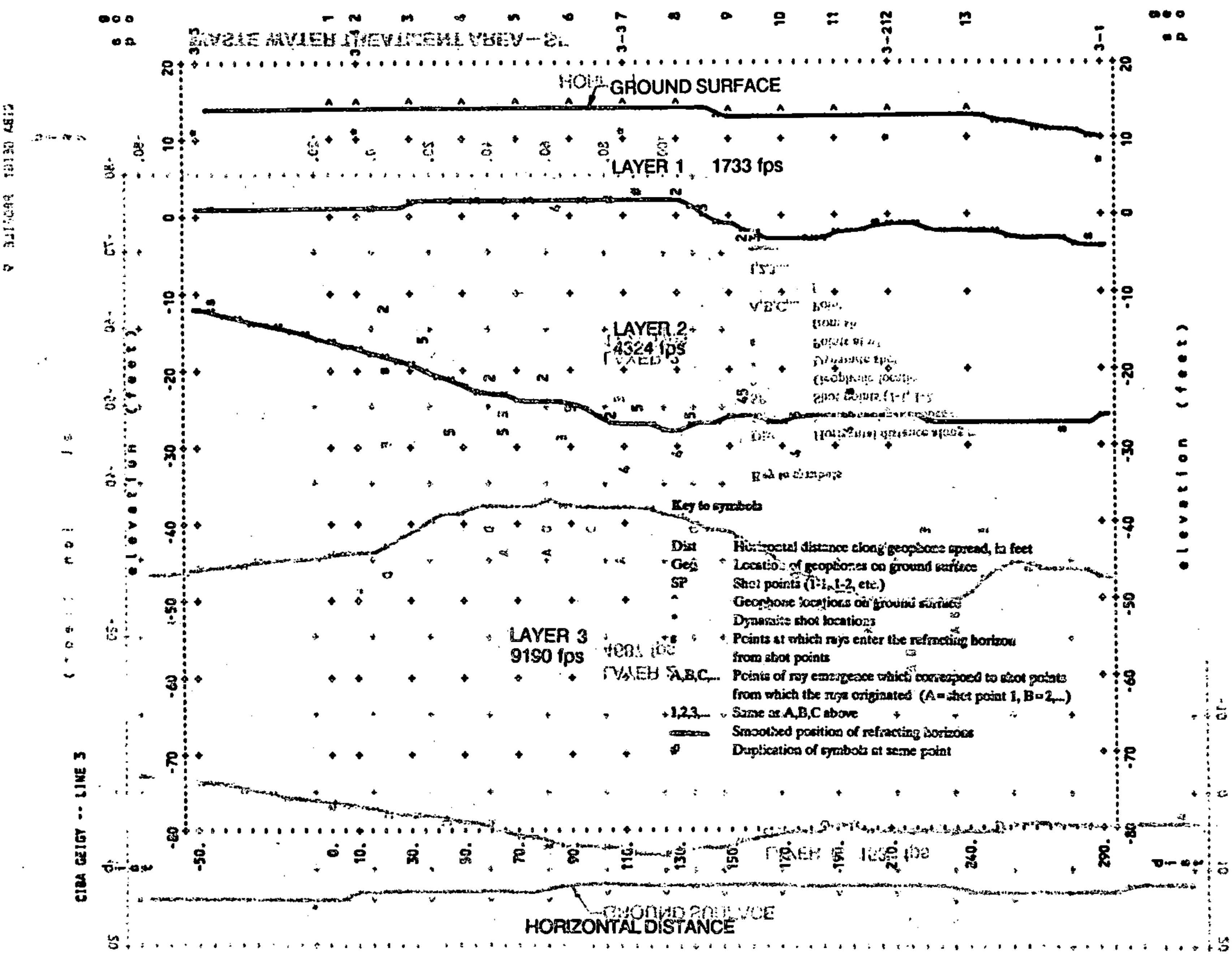
WOODWARD-CLYDE CONSULTANTS
CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS
WAYNE, NEW JERSEY

DR. BY:	KF	SCALE:	AS SHOWN	PROJ. NO.:	87X4660
CK'D. BY:	JDA	DATE:	28 SEPT 1990	FIG. NO.:	2–21



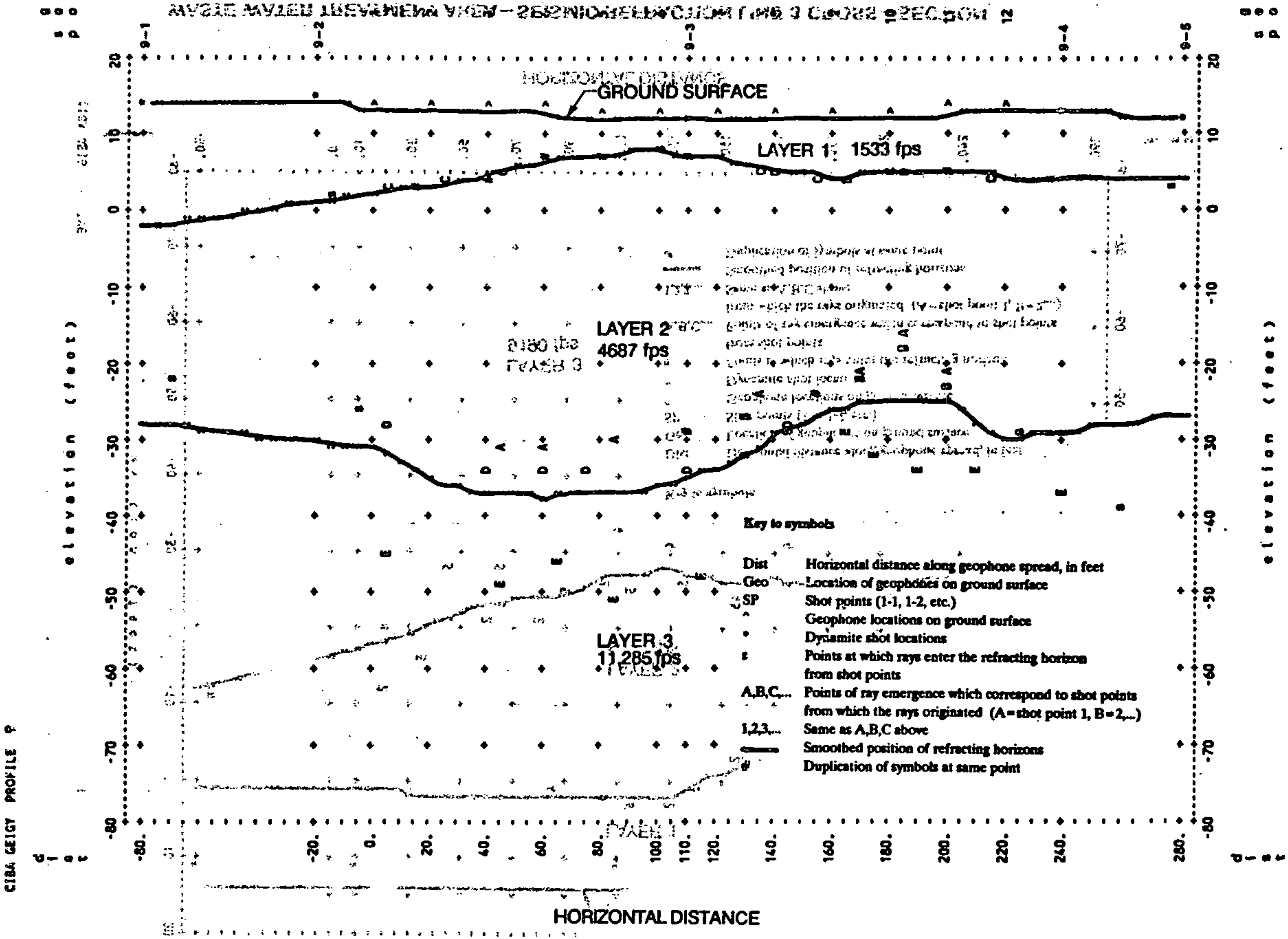
WASTE WATER TREATMENT AREA – SEISMIC REFRACTION LINE 2W CROSS-SECTION

FIGURE 2-22



WASTE WATER TREATMENT AREA—SEISMIC REFRACTION LINE 3 CROSS-SECTION

FIGURE 2—23



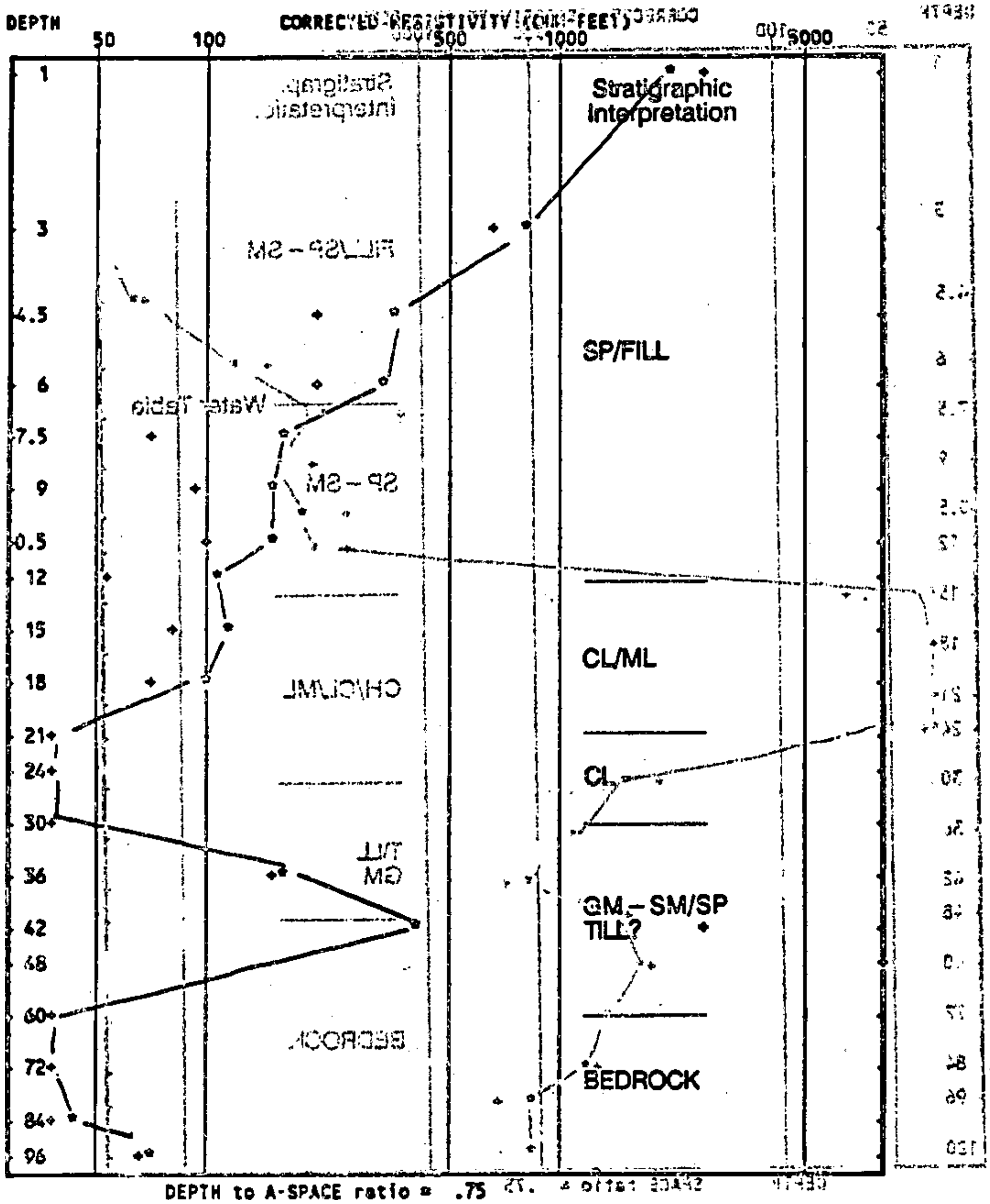
WASTE WATER TREATMENT AREA—SEISMIC REFRACTION LINE 9 CROSS—SECTION

FIGURE 2—24

FILE LABEL: cibe   STATION: Line 2

CORRECTED RESISTIVITY (OHM-FEET)

A-SPACE	DEPTH	RESIS	FULL	PARTIAL
2	0-2	X146.900	2292	1846
4	2-4	45.400	606	751
6	3-6	18.640	187	327
8	4-8	11.010	187	285
10	5-10	5.900	66	151
12	6-12	4.180	85	148
14	7-14	3.220	96	145
16	8-16	2.300	48	99
20	10-20	1.530	73	103
24	12-24	1.090	65	[illegible]
28	14-28	0.533	14	[illegible]
32	16-32	0.130	[illegible]	[illegible]
40	20-40	0.322	[illegible]	[illegible]
48	24-48	0.521	[illegible]	[illegible]
56	28-56	0.483	[illegible]	[illegible]
64	32-64	0.223	X369317.92	X179089
80	40-80	0.063	[illegible]	[illegible]
96	48-96	0.091	[illegible]	[illegible]
112	56-112	0.113	[illegible]	[illegible]
128	64-128	0.0932	[illegible]	[illegible]



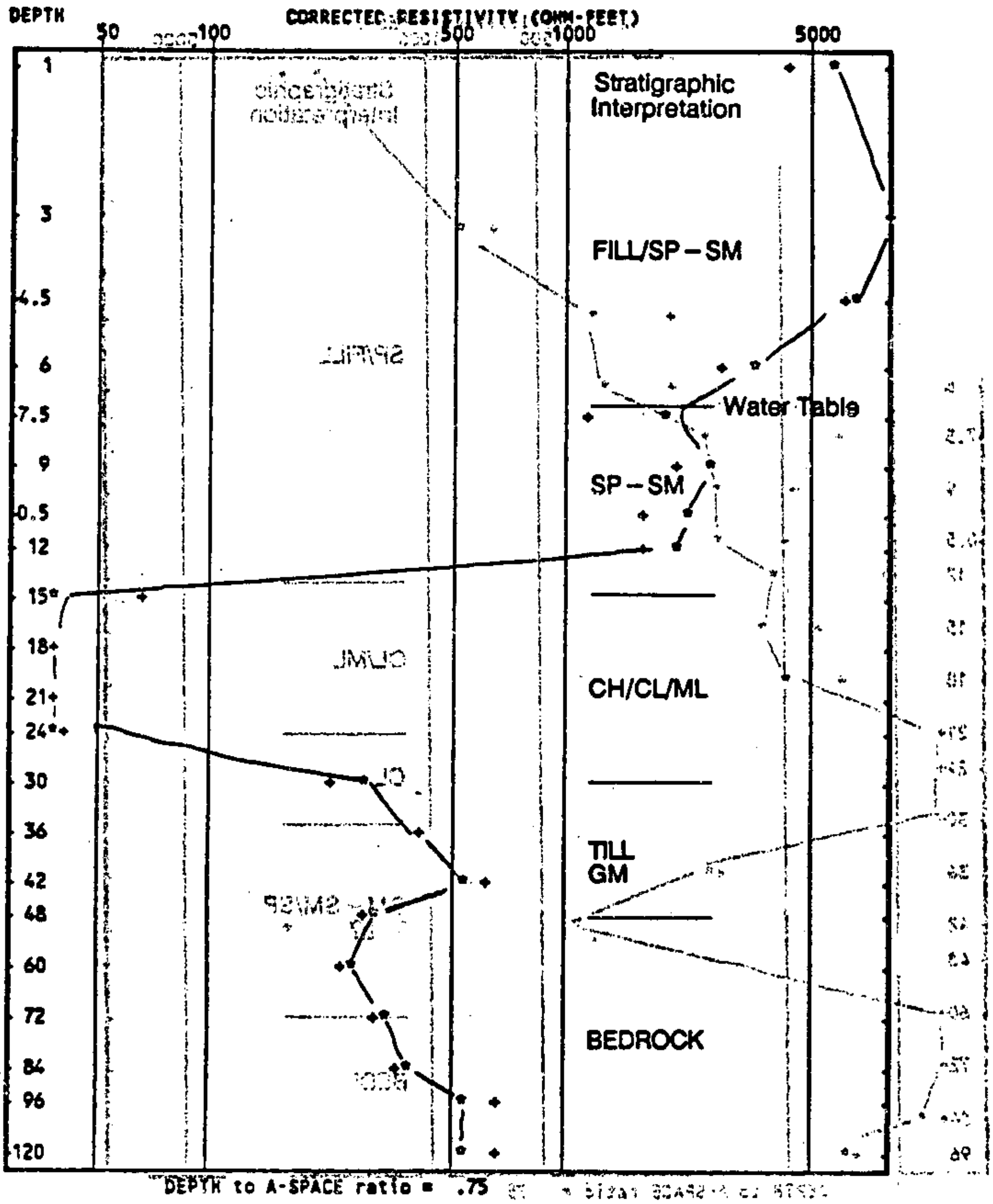
WASTE WATER TREATMENT AREA - ELECTRICAL RESISTIVITY SOUNDING 2 CROSS SECTION

FIGURE 2-25

FILE LABEL: cibe STATION: Line 3

CORRECTED RESISTIVITY (OHM-FEET)

A-SPACE	DEPTH	RESIS	FULL	PARTIAL
2	0-2	%411.600	3981	5172
4	2-4	%311.900	21452	12605
6	3-6	%181.010	5579	5947
8	4-8	95.770	2535	3149
10	5-10	57.640	1102	3782
12	6-12	52.010	1864	2404
14	7-14	36.900	1595	2038
16	8-16	29.160	1520	1903
20	10-20	5.390	61	0
24	12-24	3.240	55	0
28	14-28	1.840	25	0
32	16-32	1.760	36	0
40	20-40	1.600	200	255
48	24-48	1.210	462	625
56	28-56	1.130	565	489
64	32-64	0.770	259	274
80	40-80	0.611	317	343
96	48-96	0.550	268	582
112	56-112	0.515	321	334
128	64-128	0.436	597	500
160	80-120	0.386	586	492



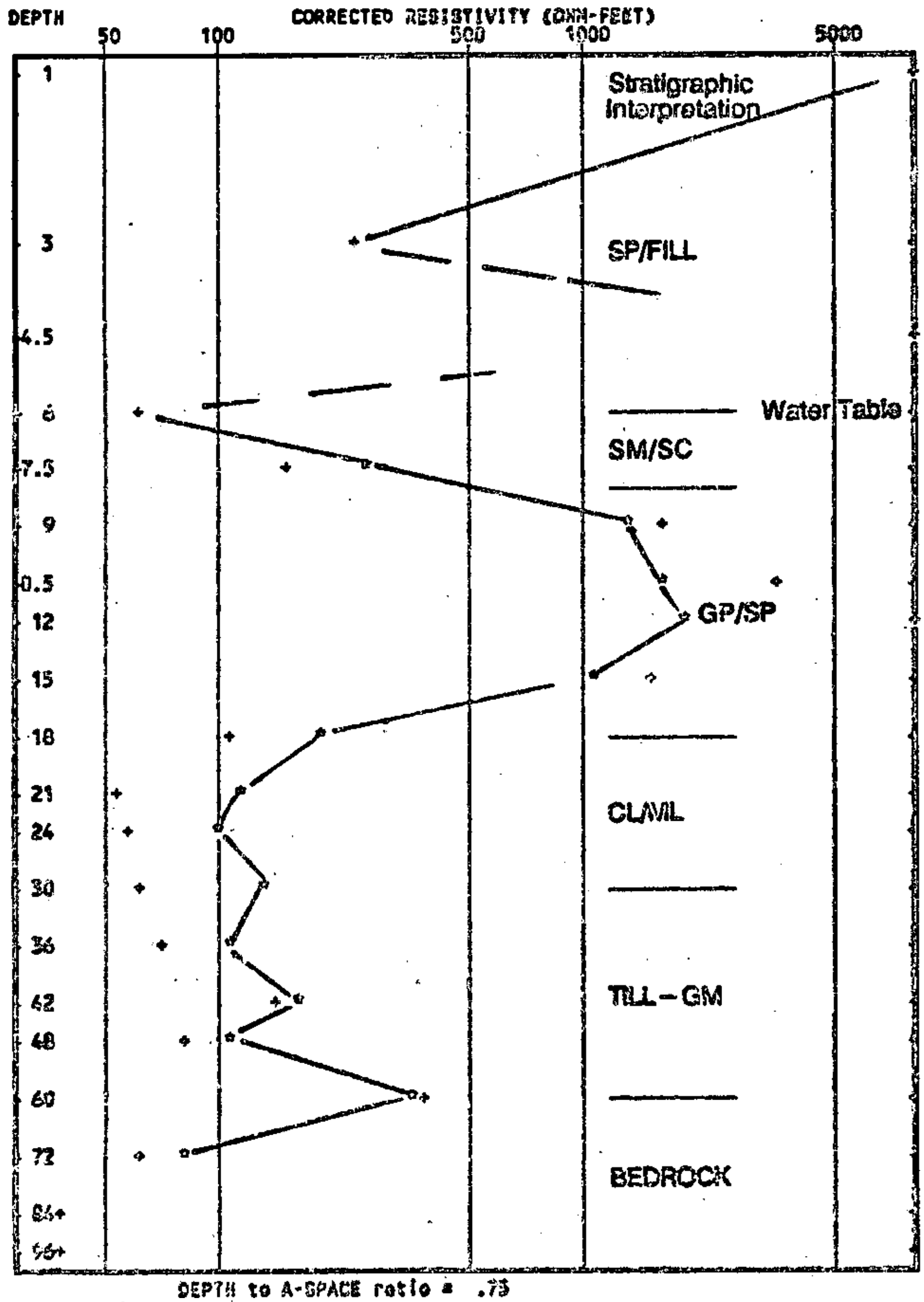
WASTE WATER TREATMENT AREA – ELECTRICAL RESISTIVITY SOUNDING 3 CROSS – SECTION

FIGURE 2–26

FILE LABEL: ciba STATION: CIBA 9

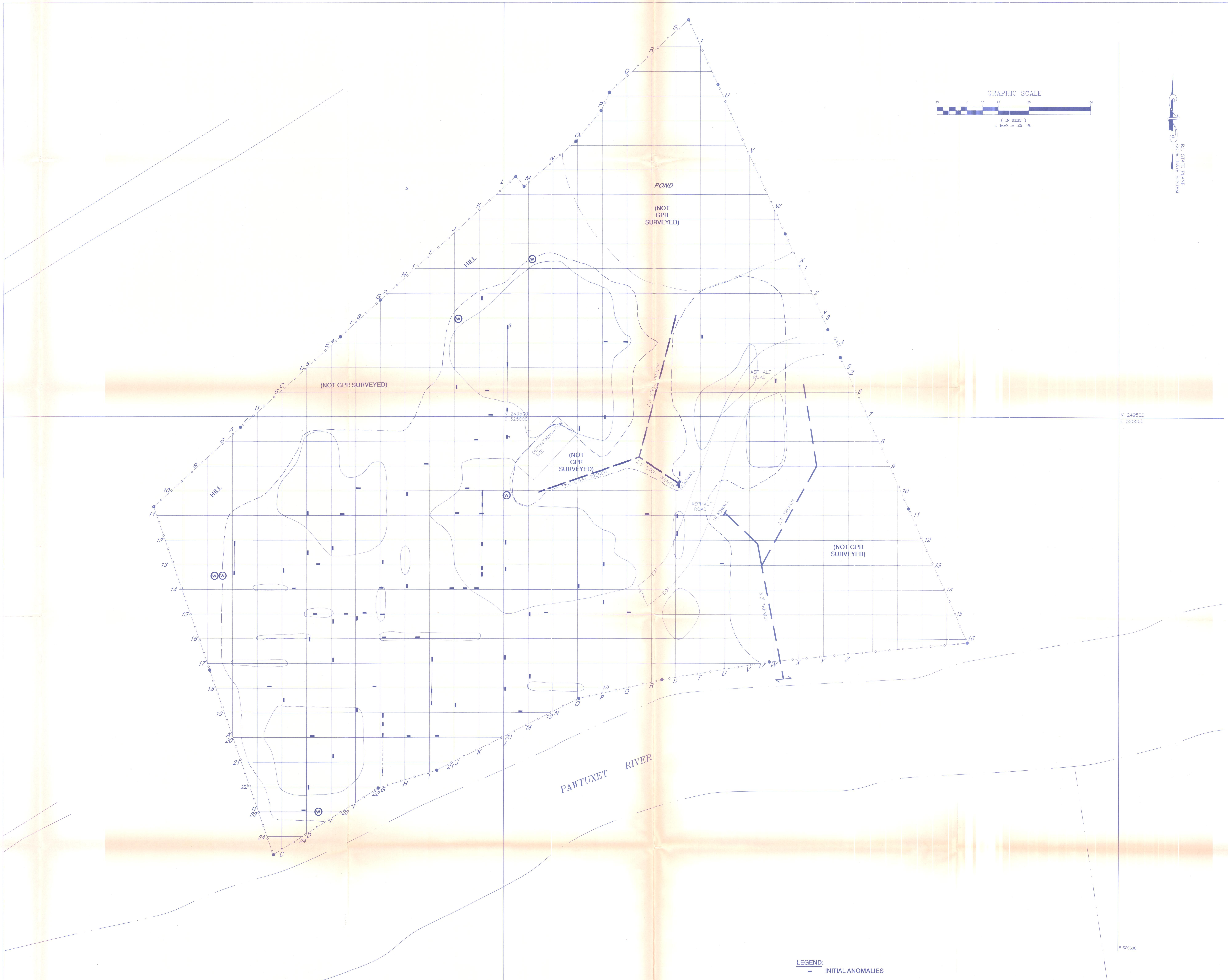
CORRECTED RESISTIVITY (OHM-FEET)

A-SPACE	DEPTH	RESIS	FULL	PARTIAL*
2	0-2	X580.130	7256	7290
4	2-4	76.950	223	222
6	3-6	17.700	X77073160	73441
8	4-8	10.130	58	56
10	5-10	7.810	141	236
12	6-12	11.890	1589	1225
14	7-14	10.450	3200	1583
16	8-16	8.850	7339	1832
20	10-20	5.530	1451	1014
24	12-24	2.630	103	183
28	14-28	1.860	48	107
32	16-32	1.530	51	91
40	20-40	1.140	56	120
48	24-48	0.640	66	100
56	28-56	0.620	129	153
64	32-64	0.420	74	99
80	40-80	0.610	339	327
96	48-96	0.190	37	73
112	56-112	0.110	11	25
128	64-128	0.090	17	32



WASTE WATER TREATMENT AREA – ELECTRICAL RESISTIVITY SOUNDING 9 CROSS–SECTION

FIGURE 2–27



GROUND – PENETRATING RADAR ANOMALIES DETECTED
WASTE WATER TREATMENT AREA
CIBA – GEIGY FACILITY
CRANSTON, RHODE ISLAND

WOODWARD-CLYDE CONSULTANTS
CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS
WAYNE, NEW JERSEY

DR. BY:	KF	SCALE:	AS SHOWN	PROJ. NO.:	87X4660
CK'D. BY:	JDA	DATE:	28 SEPT 1990	FIG. NO.:	2 – 28

Section Three

SECTION 3
GEOLOGICAL INVESTIGATION

3.1 OVERVIEW

This section of the Phase IA Report describes the results of the geological investigation. The primary objectives of the investigation focused on obtaining site-specific information to:

- o characterize the facility's geologic environment; and
- o corroborate information collected from the geophysical surveys.

Data were evaluated to characterize the regional and local geomorphology, surficial geology, bedrock lithology, and bedrock structure. These data were used to develop a model of the area and to assess the geological characteristics of the facility.

This section includes discussion of the objectives of the investigation and the methods and analyses employed. Results are presented as a discussion of regional geology, local geology, and site-specific geology. A discussion of all results and a summary conclude this section.

3.2 INTRODUCTION AND OBJECTIVES

The Phase IA geological investigation was conducted in accordance with the Facility Investigation Work Plan in Volume 1 of the RFI proposal. There were three activities:

1. a literature survey and review;
2. reconnaissance-level geological mapping of bedrock exposures; and,
3. on-site physical geological characterization activities.

The literature survey and review were conducted to place the site in its regional tectonic and stratigraphic setting and to provide a framework for planning and implementing the detailed site-specific investigation activities. Reconnaissance-level geological mapping was performed to identify lithologies and geological structures (such as faults, joints, cleavages, and metamorphic fabric) that could affect the ground water regime and could provide a mechanism (or pathway) for potential contaminant migration. Since there are no on-site surface rock exposures, the off-site geological mapping was used to identify the subsurface rock characteristics likely to occur under the site. (Surficial and bedrock geological maps of the region are presented in Chapter 1 of the RFI Proposal, Volume I).

The on-site geological characterization activities involved drilling and sampling of subsurface sediments and bedrock, and installing monitoring wells and piezometers at selected locations. The data obtained were used to evaluate the overburden and bedrock lithologies and to correlate the on-site sediment and bedrock conditions with the regional data. Bedrock cores were obtained and logged for correlation to off-site exposures and regional geology. Sediment samples were tested in the laboratory to evaluate their physical properties that might affect contaminant mobility.

3.3 METHODS AND ANALYSES

The methods and analyses used in the three activities of the geological investigation are described below.

3.3.1 Literature Survey

The literature was surveyed at the U.S. Geological Survey library in Reston, VA to:

- o obtain available information about the regional geology in the Providence, R.I. area and in the vicinity of the site;
- o establish an understanding of the geological history of the region; and,

o establish a framework for correlating site-specific geological conditions to regional geology.

The literature reviewed included USGS publications, Geological Society of America publications, and university reports.

3.3.2 Geological Mapping

Reconnaissance-level geological mapping was performed at bedrock exposures in the vicinity of the site. The closest rock outcrops are more than one mile from the site. Comparison of the mapped rock outcrops with rock cores recovered from test borings drilled at the site provided a basis for correlating the site geology to the regional geology. Rock outcrops were selected after reviewing both the Geological Map of the Providence Quadrangle, Rhode Island (USGS, 1959) and the Guidebook to Geological Field Studies in Rhode Island and Adjacent Areas (New England Intercollegiate Geological Conference, University of Rhode Island, 1981).

Geological mapping consisted of describing the lithologies (rock types) of the exposed rock and measuring the strike and dip orientations of the rock units. Structural features such as joints, faults, bedding, and/or foliation were noted; strike and dip orientations also were recorded. Representative samples were collected for comparison to bedrock core samples obtained at the site.

3.3.3 On-Site Geological Investigation

The Phase IA site characterization activities consisted of drilling, sampling, and logging seven test borings. Four of the borings, RW-1 through RW-4, were completed as bedrock monitoring wells. Well screens were installed in the underlying rock units in borings RW-1 and RW-3. Borings RW-2 and RW-4 were completed as open-hole monitoring wells in rock. The remaining three borings were completed as deep piezometers (P-19D, P-21D, and P-22D), with well screens installed in overburden sediments overlying the bedrock. Sediment and rock samples were logged and described in the field (with follow-up laboratory testing of selected sediment samples).

The borings were drilled and sampled in conformance with the Sampling Procedures described in the Quality Assurance Plan (RFI Proposal, Volume 2). Field conditions dictated certain changes in plans, such as final boring locations and sampling of overburden sediments. All changes in plan were approved by USEPA and documented in the monthly progress reports for the project. The borings were drilled with truck-mounted CME-75 and Diedrich D50 drill rigs using hollow-stem auger methods in the overburden sediments and diamond coring methods in rock. Overburden sediment samples were obtained with a 2-inch outside diameter split-spoon sampler. Rock samples were obtained by coring with a 5-foot long NX-size (2.125-inch inside diameter) diamond bit core barrel. Overburden sediment samples were preserved in sealed glass jars for subsequent laboratory testing; recovered rock cores were placed in wooden core boxes for preservation.

3.4 RESULTS OBTAINED

The results of the literature survey, the geological mapping activities, and the on-site physical geological characterization are discussed below.

3.4.1 Regional Geology

Southeastern New England is in the Appalachian Mountain belt which is subdivided into numerous geological provinces on the basis of structural, lithologic, and radiometric-age differences of bedrock.

The site is located in the west-central part of a geological province known as the Narragansett Basin. This partly fault-bounded basin, extending from southeast Massachusetts to southeast Rhode Island, was a late orogenic, structural and topographic basin. During the Late Pennsylvanian period (about 290 million years ago [mya]), the basin received rapid influxes of nonmarine, clastic sedimentary rocks in association with contemporaneous volcanic rocks and granitic intrusions (Hepburn and Rehmer, 1981). The sedimentary lithologies range from feldspathic shales and sandstones to conglomerates (Quinn, 1971). The rocks are locally fossiliferous (plant fossils) and can therefore be relatively dated on the basis of fossils. The western and eastern margins of the basin exhibit unconformable relationships with the underlying older rocks (Hepburn and Rehmer, 1981).

The basement rocks underlying the Narragansett Basin consist of Precambrian and Lower Paleozoic metamorphic and igneous rocks. The eastern portion of the basin overlies the foliated Bulgarmarsh Granite and undifferentiated schists (Galloway, 1973). A heterogenous assemblage of gneisses, granites, metasedimentary, and metavolcanic rocks underlie the western reaches of the basin (Mosher and Wood, 1976). Much of the basement rocks underlying the western portion of the basin have been referred to as the Blackstone Series. Rocks associated with the Blackstone Series are exposed several miles northwest of the CIBA-GEIGY facility. Those rocks, which make up the Precambrian basement terrain, are high-grade meta-igneous and meta-sedimentary rocks that were emplaced and subsequently metamorphosed about 600 mya.

Narragansett Basin rocks have been faulted, folded, and metamorphosed to grades ranging from diagenesis (incipient metamorphism) to upper amphibolite facies. Attempts to correlate structural deformation and metamorphism directly have not been successful (Hepburn and Rehmer, 1981). Structural deformation and metamorphism of the basin rocks occurred during the Alleghenian orogeny, a localized tectonic event that occurred during the Permian period about 275 mya (Skehan and Murray, 1980). The southern portion of the basin underwent the most intense deformation, resulting in the development of tight isoclinal to recumbent north-to-northeast trending folds and north-to-northwest trending faults. Metamorphic grade of basin rocks generally increases from north to south (Barosh and Hermes, 1981).

The dominant bedrock unit in the Narragansett Basin is the Pennsylvanian-aged Rhode Island Formation, estimated to be about 10,000 feet thick (Quinn, 1971). The formation primarily consists of gray and black conglomerates, sandstones, and shale, with minor amounts of coal. The depositional setting is interpreted to be fluvial (Quinn, 1971). Coarse conglomeratic layers are somewhat more resistant to erosional processes, so they are generally associated with topographic highs (and possibly with subsurface highs). The Rhode Island Formation exhibits varying degrees of folding, faulting, and jointing, and is partially metamorphosed. Alteration varies from diagenetic grade to the amphibolite facies of metamorphism. Illite crystallinity studies on the lower grade rocks of the Rhode Island Formation have been performed (Hepburn and Rehmer, 1981). The results show that bedrock at the CIBA-GEIGY site should exhibit texture and mineralogy intermediate between diagenesis and the greenschist facies of metamorphism.

The topography and overburden sediments of the region have been strongly influenced by Pleistocene glaciation and post-Pleistocene fluvial erosional and depositional processes. Overburden sediments in the region consist primarily of glacial outwash that includes layers of clay, silt, sand, and gravel (Moultrop, 1956). Several geomorphological land forms associated with glacial processes are present, such as kames, kame terraces, kame plains, and ice channel fillings (Smith, 1956). The glacial outwash is generally found overlying bedrock in thicknesses up to 280 feet in most lowland areas. In some highland areas outwash is not present (Bierschenk, 1959). The Pawtuxet River flows along the boundary between the Providence outwash plain to the north and the Warwick outwash plain to the south. The glacial outwash has been variably eroded in stream and river valleys, and has been reworked (or redeposited) as fluvial and/or alluvial sediments.

3.4.2 Local Geology

The unconsolidated deposits in the vicinity of the site generally have thicknesses that range from 50 to 100 feet (Bierschenk, 1959). The typical stratigraphy in areas near the facility, as described by Bierschenk, consists of a layer of fill that is underlain by a layer of sand and gravel of variable thickness, which in turn is underlain by a layer of silt.

Scattered pockets of Recent alluvial deposits occur in areas east of the site. Those deposits consist of stratified clays, silts, sands, and gravels which typically represent outwash materials that were reworked (redeposited) by the Pawtuxet River (Moultrop, 1956). West of the site, small isolated pockets of material having a high organic content occur adjacent to the Pawtuxet River. Those deposits are found in low marshy areas where the water table is near the ground surface. The underlying sediments, however, are generally similar to the typical outwash found in surrounding areas (Moultrop, 1956).

Rock outcrops within a few miles of the site contain exposures of the Rhode Island Formation. Primarily, the exposed rocks are partially metamorphosed sandstones and phyllites (metamorphosed shales -- transitional between slate and schist). The outcrops exhibit folds, joints, foliation, and cleavage. The attitude of the rock units is variable, although the predominant strike orientation is generally in a northwesterly-southeasterly direction. The dip ranges from less than 30° from horizontal to as much as 60°, in both northeasterly and southwesterly directions. The attitude of cleavage (i.e., dip angle of the foliation of the rock units) depends on the amount of folding of the rock units in a given locality. Joint orientations tend to be parallel to the general rock structure; although there are some joints that strike and dip across the major trend.

3.4.3 Site-Specific Geology

The site lies within the flood plain of the Pawtuxet River. The site topography is typical of low-lying flood plains, with relief ranging from about 10 to 25 feet above sea level. Much of the site lies within the 100-year flood plain of the Pawtuxet River.

The site is generally overlain by a variably thick mantle of miscellaneous man-made fill. Where present, the fill overlies overburden sediment consisting of sands, silts, clays, gravels, or combinations thereof. The overburden sediments generally overlie glacial till, although till was not identified in all the borings drilled to date. Where till was not observed, the overburden sediments overlie bedrock. Where till is observed, till overlies bedrock. The bedrock observed in Phase IA test borings is partially metamorphosed sandstones and phyllites. Figure 3-1 shows the Phase IA boring locations and section lines for the geological cross-sections. The geological cross-sections developed from the results of the boring program are shown on Figures 3-2, 3-3, and 3-4. The logs for the Phase IA borings are presented in Appendix D.

Fill

The man-made fill is variable in nature and thickness, and includes sands, silts, organic soils, construction debris, and asphalt. The observed thickness of fill in the test borings was variable. Fill was not identified in borings RW-4, P-19D, and P-21D (Figure 3-1). The thickness of fill in borings RW-1, -2, -3, and P-22D ranged from about 2 feet to 14 feet. The consistency of the fill ranges from very loose to very dense. The water table was first encountered between about 4 feet to 14 feet below the ground surface.

Overburden Sediments

The overburden sediments consist of fine to coarse-grained sands, silty sands, silts, clays, and gravels. Samples were visually classified in the field in general conformance to the Unified Soils Classification System (Lambe and Whitman, 1979). The overburden sediments encountered in borings RW-1 and RW-4 (the Production Area and slightly east of the Production Area) were sandier than sediments encountered in either the Warwick Area or the Waste Water Treatment Area (Figure 3-1). The stratigraphy in RW-1 and RW-4 is consistent with the boring log for P-14D, a boring drilled in the Production Area during the Preliminary Investigation (see Figures 3-2, 3-3, and 3-4).

Borings RW-2 and P-19D were drilled close to the river in the Waste Water Treatment Area (Figure 3-1). These borings encountered finer-grained sediments (i.e., silts, clays, and combinations thereof) than the borings in the Production Area. The vertical lithologic sequence observed in boring P-19D is somewhat similar to those observed in borings MW-8S and MW-9S (drilled during the Preliminary Investigation), but P-19D has generally finer-grained sediments. Boring RW-2 was drilled in the vicinity of MW-8S, but did not encounter sandy units.

The three borings drilled south of the Pawtuxet River in the Warwick Area (Figure 3-1) encountered much less sand than boring MW-6S (drilled during the Preliminary Investigation). The lithologic sequences in borings P-22D and RW-3 are dominated by silty and clayey units, but some sand units were present at shallow depths. A loose, saturated silty, fine sand was encountered in boring RW-3 at a depth of about 57.5 feet. This sand became quick (a flowing, unstable condition) and flowed up into the hollow-stem auger. For that reason, it was not possible to collect samples from a depth of about 58 to 68 feet. The top of bedrock was encountered at 68 feet. Casing was driven to 73 feet to begin rock coring operations. Sand and clayey or silty sediments were encountered in boring P-21D in approximately equal proportions.

Glacial Till

Glacial till is a sediment characterized by a dense to very dense consistency and ranging in grain size from clays to poorly sorted sands, gravels, cobbles, and boulders. The till observed in the Phase IA borings is dense to very dense, or stiff to very stiff, gravelly sands or silts/clays. The till layer is of a variable thickness.

Glacial till was identified in four of the Phase IA borings. The till ranged in thickness from about 4 feet to 12 feet. Two borings (P-19D and P-21D, Figure 3-1) encountered rock fragments in the last samples taken in each boring. These rock fragments may represent bedrock. Where identified, the till was found to overlie bedrock. The top of till was identified in borings RW-1, RW-2, RW-4, and P-21D at elevations of -33, -31, 1, and -23 feet relative to Mean Sea Level (MSL), respectively. Boring P-14D (drilled during the Preliminary Investigation) encountered the top of glacial till at about -22 feet relative to MSL.

Bedrock

The four borings designated as RW-1 through RW-4 (Figure 3-1) encountered bedrock; rock core was recovered. Two borings, P-19D and P-22D, may have been terminated at the top of bedrock. Bedrock was encountered at approximate elevations of -45, -34, -55, and -4 feet MSL in borings RW-1 through RW-4, respectively. Borings P-19D and P-22D may have encountered rock at about elevations -17 and -44 feet MSL, respectively. Boring P-14D may have encountered rock at about elevation -34 feet MSL, but did not core into bedrock.

A flowing sand condition was encountered during rock coring in borings RW-1 and RW-4 (Figure 3-1). In RW-1, this condition occurred after coring approximately 2 feet into the upper portion of bedrock. In RW-4, the flowing sand condition occurred approximately 5 feet into the bedrock. Sand samples collected from the return wash water consisted of very fine- to fine-grained silty sand. As a result of the flowing sand condition in boring RW-1, an additional boring was drilled approximately 15 feet north of the original RW-1 and advanced to the desired depth into rock for installation of the monitoring well casing and screen.

Bedrock lithology at the site is consistent with regional descriptions of the Pennsylvanian age Rhode Island Formation. Bedrock, as described from the recovered rock cores, is primarily a fine- to medium-grained quartzitic, metamorphosed sandstone. Foliation is moderately- to well-developed and dips at angles ranging from about 30° to over 60° from the horizontal. Strike orientation of the bedrock cannot be determined from unoriented rock core. The cores exhibit joints and fractures that tend to be parallel to the foliation. Fracture surfaces exhibit quartz or clay/mica mineralization, and are occasionally iron-stained. Weathering of the rock is generally confined to joints and broken zones, although the rock from the one core run completed at RW-1 is moderately- to deeply-weathered. Thin phyllitic layers are present in the metamorphosed sandstone, probably indicating that shale interbeds also exhibit low grade metamorphic texture.

Metamorphosed shale and quartzitic conglomerates also were encountered in the rock cores. These lithologies also exhibited moderately- to well-developed foliation with subparallel joints or fractures.

Intergranular porosity in the bedrock appears to have been reduced by quartz cementation and partial metamorphism. Therefore, the most effective porosity in the bedrock is probably within joints and fractures (i.e., secondary porosity).

Laboratory Testing for Geotechnical Properties of Overburden Sediments

Laboratory testing was performed on selected overburden sediment samples from the borings in accordance with the procedures identified in the Quality Assurance Plan, Volume 2 of the RFI Proposal. Tests performed on undisturbed samples (Shelby tubes) and disturbed samples (split-spoon samples) included:

- o dry bulk density,
- o porosity,
- o hydraulic conductivity, and
- o grain size distribution.

Each of the above tests were performed on eleven Shelby tube samples from the Phase IA borings. In addition, density, porosity, and hydraulic conductivity analyses were performed on two remolded Shelby tube samples from boring P-22D. Twenty-one grain size analyses were performed on split-spoon samples. In addition, grain size analyses were performed on two flowing-sand samples. The visual Unified Soil Classification (USCS) made in the field is generally consistent with the laboratory results.

Dry bulk densities of the overburden sediment range from about 80 pounds per cubic foot (pcf) to 110 pcf. Porosities range from about 26 to 46 per cent for the undisturbed samples. Hydraulic conductivity results for undisturbed sediments range from about 4×10^{-4} cm/sec (sandy sediments) to 8×10^{-8} cm/sec (clayey sediments). The laboratory data and grain-size distribution curves are included in Appendix E.

3.5 DISCUSSION

The data from the Phase IA geological investigation show that the site geological conditions generally conform to published regional geological models, and that overburden stratigraphy is more complex than might have been expected from the Preliminary Investigation.

The overburden sediments consist of discontinuous interbedded sands, silts, clays, and combinations thereof. Many individual units do not exhibit lateral continuity between borings. The lack of lateral continuity is more pronounced based on the Phase IA borings than was apparent during the Preliminary Investigation. The stratigraphic section at the site may include glacial outwash sediments and/or reworked glacial outwash sediments redeposited in a fluvial system. At the present time, there is insufficient evidence to distinguish between glacial outwash sediments and fluvial sediments.

The glacial till identified in the deeper borings is consistent with the descriptions of till in the literature. The variable depths and thickness of the till may be caused by syndepositional topographic relief, various glacial processes, and/or post-depositional erosion.

The bedrock characteristics logged from the recovered rock core are consistent with the rock outcrops of the Rhode Island Formation observed in this study. In addition, the characteristics are consistent with published descriptions of the Rhode Island Formation. The formation is sedimentary in origin (sandstones, shales, and conglomerates) and has been subsequently metamorphosed and deformed.

Field observation of Rhode Island Formation outcrops indicates that a planar feature tentatively identified as bedding is steeply dipping at the location of the outcrops. However, bedding planes were not visible in the rock core retrieved at the facility, and the dip angles of foliation are not necessarily the same as the bedding dip angles. Extensive folding is reported in the literature for the Rhode Island Formation (Barosh and Hermes, 1981). In folded rocks, beds may be flat-lying in some areas and steeply dipping in other areas, depending on the proximity to the axial plane of the fold. Therefore, it is not known whether the Rhode Island Formation is flat-lying or dipping underneath the site.

The geophysical data compare favorably with the boring data. The electrical resistivity survey data suggest interbedded sands, silts, and clays that are laterally discontinuous. Glacial till is relatively well defined in the electrical resistivity data. The upper portion of the bedrock (Rhode Island Formation) appears to have lower resistivity than might be expected. Lower resistivity may be caused by brackish formation water, which was previously found in the Rhode Island Formation at other subsurface locations (Frimpter and Maevsky, 1979).

The interbedding and gradational lithology types observed in the overburden sediments reduce the sensitivity of the seismic refraction method for differentiating these sediments. The seismic velocities of the glacial till and underlying bedrock appear to be similar, ranging from about 8600 feet per second (fps) to greater than 12,000 fps. This similarity in seismic velocities makes it difficult to differentiate till and bedrock by seismic refraction methods. In addition, the lithologic variability in the overburden sediments precludes differentiation between refractive layers. In general, the seismic data suggest that the top of bedrock ranges in depth from about 45 to 60 feet below the ground surface.

3.6 SUMMARY

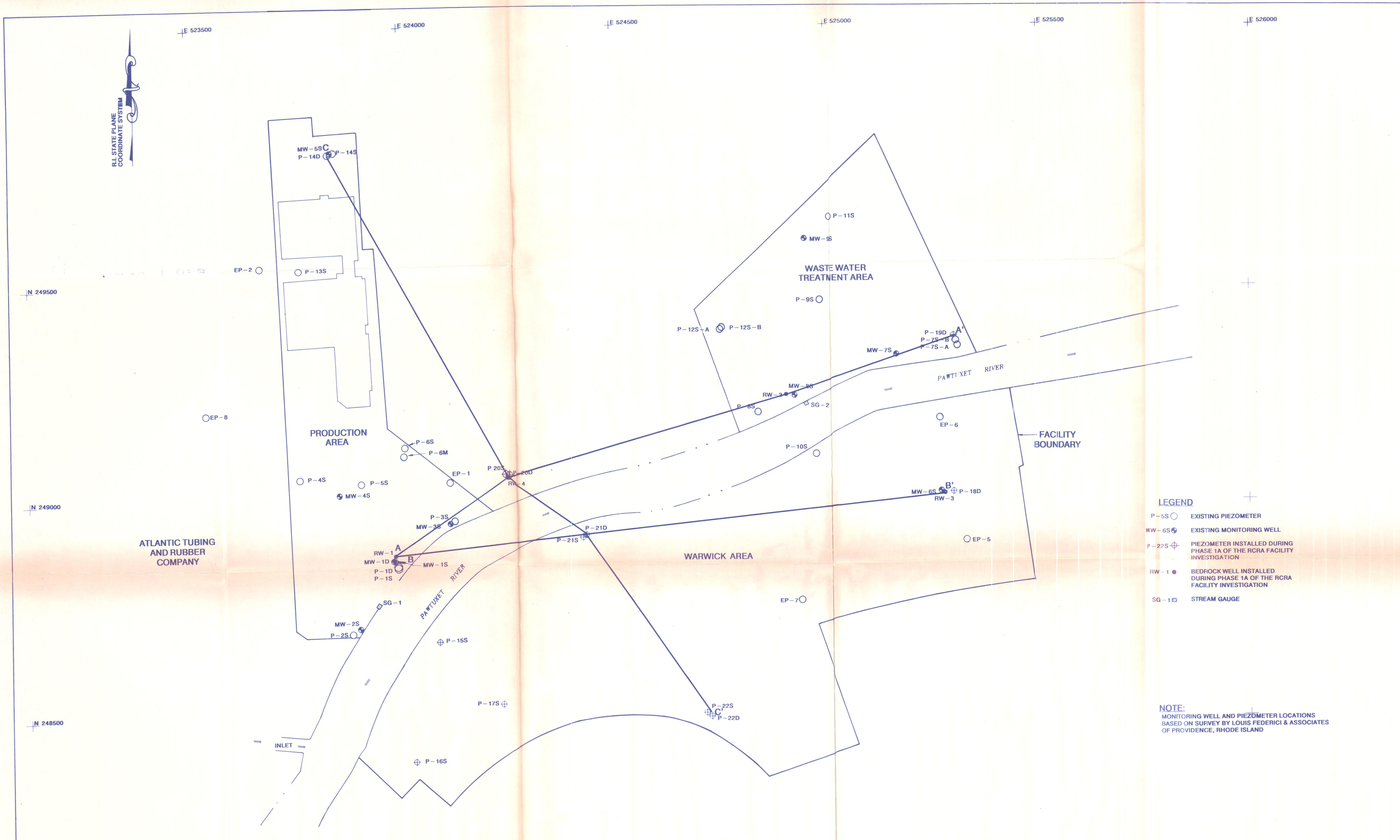
The Phase IA geological investigation has shown that the subsurface conditions at the site generally conform to published regional geological models, and that the overburden sediment stratigraphy is more complex than had been suggested by the Preliminary Investigation data. The sediments consist of interbedded sands, silts, clays, and gravels, some of which are laterally discontinuous. It was not possible to establish the relative importance of glacial processes versus fluvial processes in the deposition of the overburden sediments.

The top of glacial till appears to exist at depths of about 25 to 60 feet, and the till thickness ranges from less than 10 feet to about 30 feet. Lithologically, the till is composed of silts, clays, and gravelly sands.

Bedrock appears to be the Rhode Island Formation, consisting of metamorphosed sandstones and shales. Depth to the top of bedrock ranges from 28 to about 60 feet. The shallowest bedrock is located at RW-4, and it appears to be a subsurface ridge or knob.

The seismic refraction and electrical resistivity data are reasonably consistent with the boring data. However, the seismic refraction method was not as sensitive in the overburden sediments because of the laterally discontinuous and lithologically gradational nature of these sediments. In addition, the similar seismic velocities of the till and bedrock complicate the differentiation of these units by the seismic refraction method.

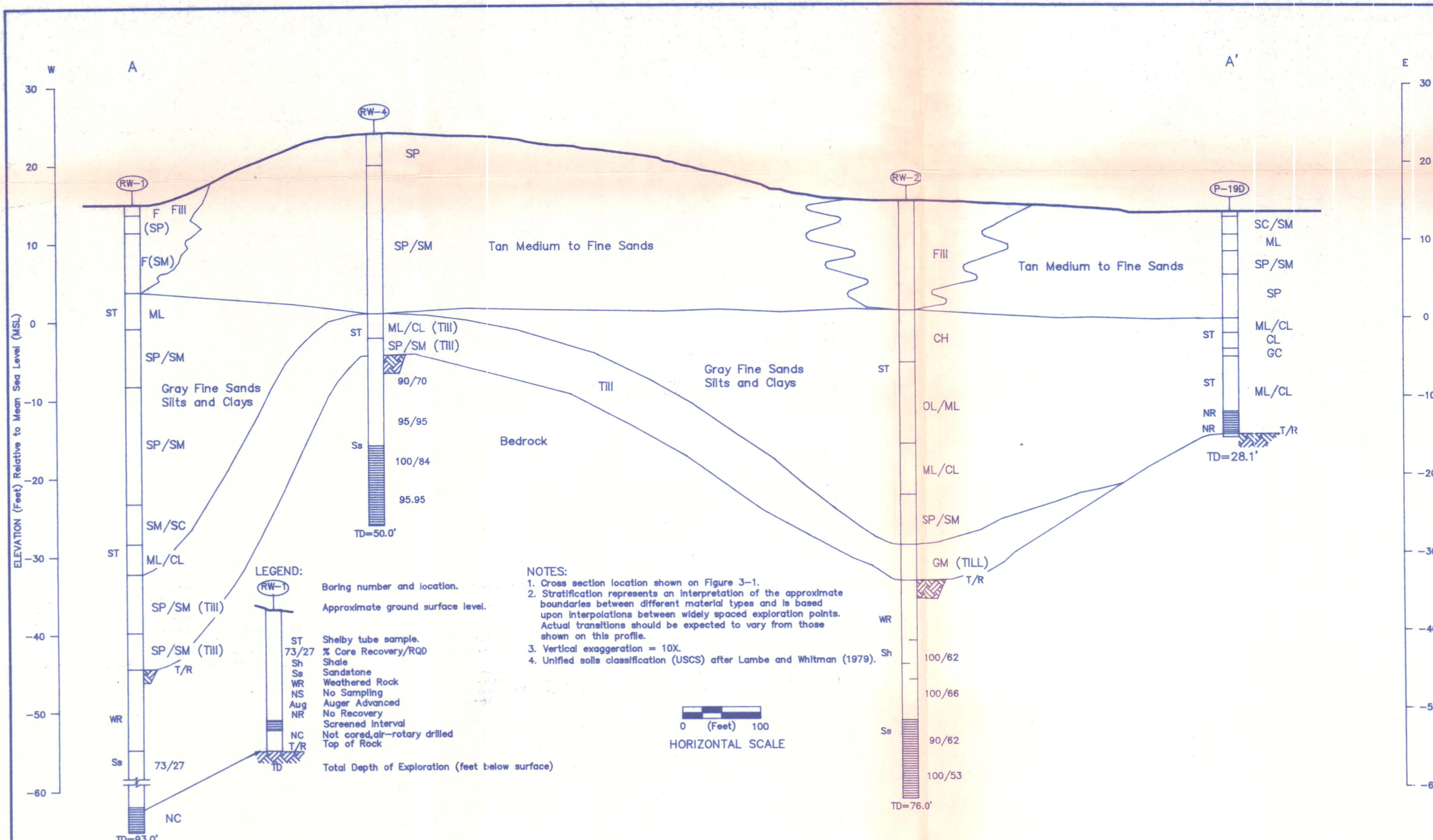
This section described the results of the geological investigation. The following section describes the hydrogeology of the site based on the results from boring data, well/piezometer installation, slug testing, and piezometric maps.



LOCATION OF GEOLOGIC CROSS-SECTIONS
A-A', B-B', AND C-C'
CIBA-GEIGY FACILITY
CRANSTON, RHODE ISLAND

WOODWARD-CLYDE CONSULTANTS
CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS
WAYNE, NEW JERSEY

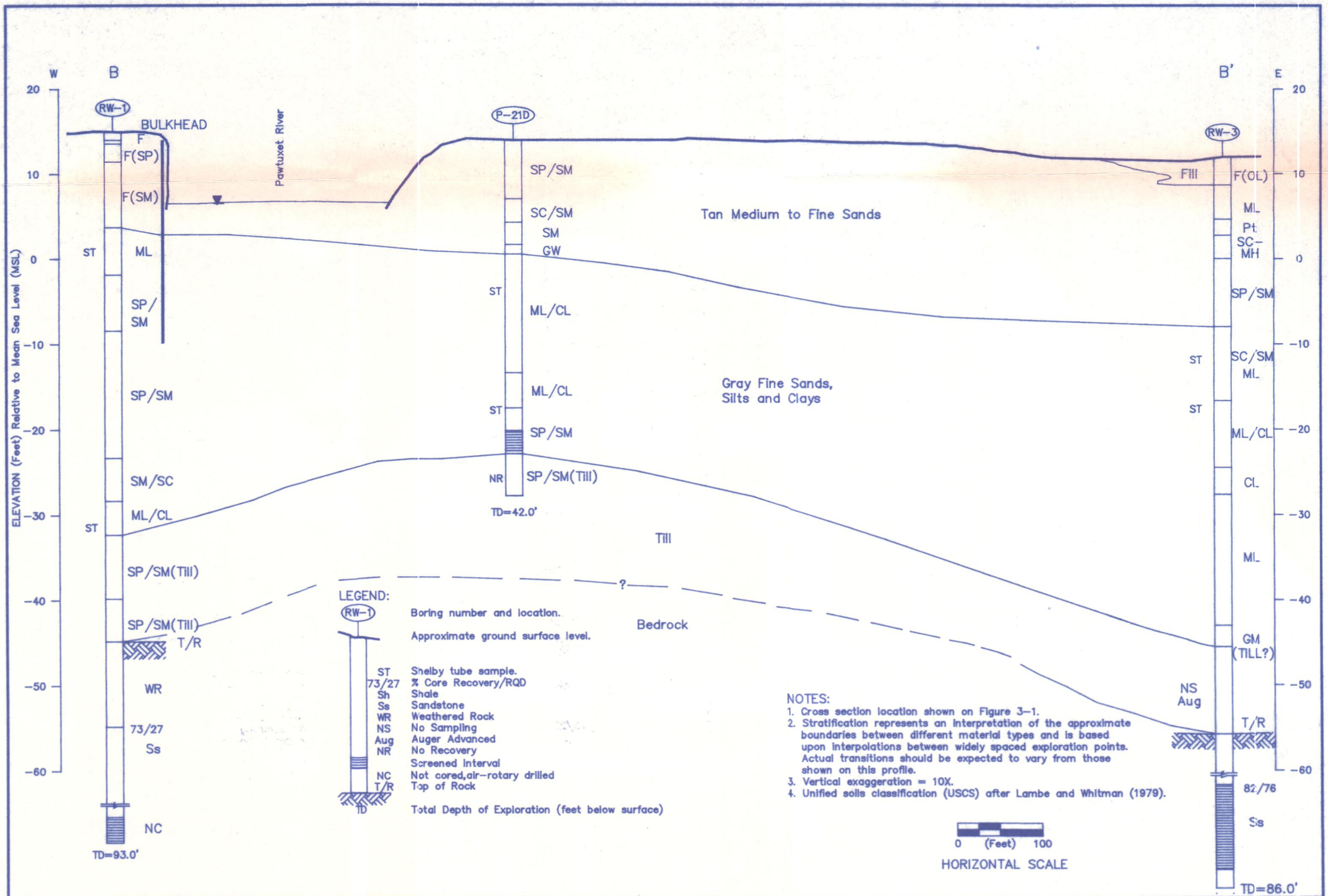
DR. BY	MG	SCALE	1: 1200	PROJ. NO.	87X4660
CK'D BY	CWT	DATE	SEPT 21 1990	FIG. NO.	3-1



PROJECT: CIBA-GEIGY
PROJECT NUMBER: 87X4660

GEOLOGIC CROSS-SECTION A-A'

Fig. 3-2



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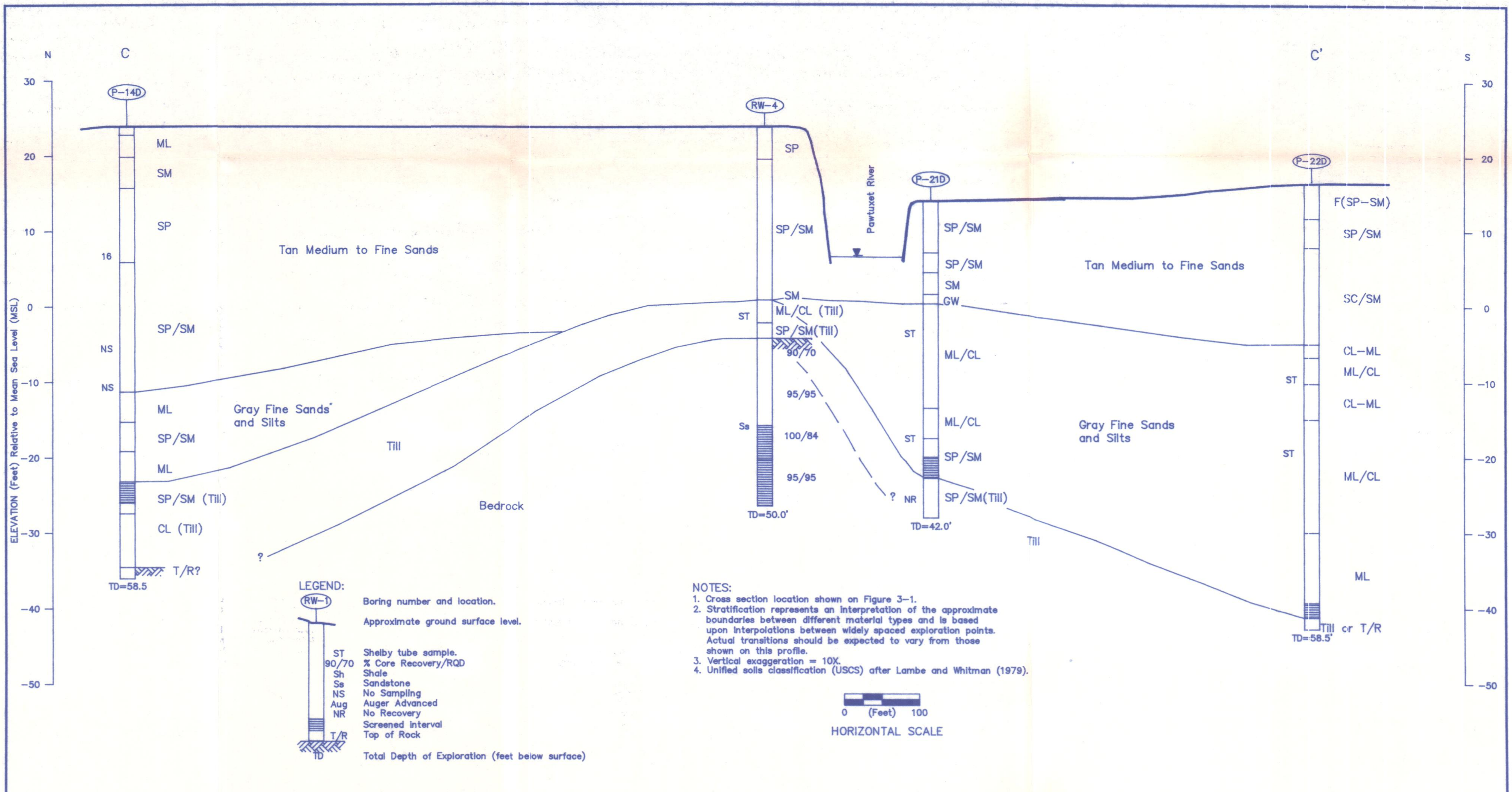
PROJECT NUMBER: 87X4660

GEOLOGIC CROSS-SECTION B-B'

Fig. 3-3



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PROJECT NUMBER: 87X4660

GEOLOGIC CROSS-SECTION C-C'

Fig. 3-4

Section Four

SECTION 4

HYDROGEOLOGICAL INVESTIGATION

4.1 OVERVIEW

A hydrogeological investigation was conducted to evaluate and characterize further the bedrock and overburden aquifers at the CIBA-GEIGY facility. Data used in the investigation included data from other Phase I investigations as well as boring log, slug test, grain size distribution, and water level measurement data.

The Preliminary Investigation conducted at the site collected and evaluated hydrogeological data (RFI Proposal, Volume 1). Most of the data and conclusions from the Preliminary Investigation pertained to the shallow part of the overburden aquifer. The inferred direction of ground water flow was toward the river. Horizontal and vertical potential gradients were calculated (0.005 to 0.016 feet and 0.011 to 0.027 feet of potential water movement per linear foot, respectively). The vertical potential gradient within the overburden aquifer was downward near the bulkhead, but was upward in the northern part of the Production Area. No data about on-site bedrock aquifer conditions were collected during the Preliminary Investigation.

This section first discusses the objectives and methodology of the hydrogeological investigation. Then the results of the investigation are reported, including the definition of hydrostratigraphic units, the measurement and/or calculation of hydraulic conductivity values, and an evaluation of the potentiometric surface in the aquifers. Finally, the section discusses the results and concludes with a summary.

4.2 INTRODUCTION AND OBJECTIVES

The hydrogeological investigation in Phase IA included three main activities. First, a literature review was performed to obtain information about aquifers in the Cranston-Warwick area. Second, 15 new wells and piezometers were installed. Third, water level data from all existing wells and piezometers were collected, compiled, and evaluated.

The overall goals of the hydrogeological investigation for all of Phase I are:

- identification of appropriate locations for monitoring wells;
- evaluation of ground water flow direction and gradients;
- development of a working hypothesis for aquifer types and boundaries; and
- evaluation of the hydraulic conductivity of stratigraphic units.

These goals were partially satisfied during this investigation, but additional data will be required before an integrated hydrogeological conceptual model of the site can be developed.

4.3 METHODS AND ANALYSES

The Current Assessment Summary Report (RFI Proposal, Volume 1) summarizes the conclusions from Bierschenk (1959) regarding the regional characteristics of the overburden and bedrock aquifers. Further literature searches conducted during the Phase IA investigation yielded no additional references. Personnel at the United States Geological Survey-Water Resources Division (USGS-WRD) were consulted about any professional papers, water supply papers, or open-file reports available about the aquifers. With the exception of a paper concerning coal-mining in the Narragansett Basin, the USGS-WRD personnel indicated that no information was available.

Eleven drive-point piezometers were installed during July 1990 (eight in the Warwick Area, two between the Production Area and the Waste Water Treatment Area, and one in the Waste Water Treatment Area) as shown in Figure 4-1. Shallow piezometers were installed approximately 5 feet below the water table, and deep piezometers were installed just above the till or bedrock.

In general, the procedures for installing the drive-point piezometers were as follows. Piezometers were placed in an augered borehole and then driven for the last 5 feet. Materials used for the piezometers included threaded 1.25-inch inside diameter riser pipe and screens. The riser pipes were galvanized steel; the screens were 7.5-slot (0.0075-inch) stainless steel. No engineered filter packs were used. Protective surface casings were installed. Point piezometers were finished with continuous-pour concrete caps and aprons, identifying decals, and locks. Drive-point piezometer installation procedures are outlined in the Quality Assurance Plan (RFI Proposal, Volume 2).

Four monitoring wells were installed in the bedrock aquifer -- one each in the Production Area, the Waste Water Treatment Area, the Warwick Area, and the area between the Production Area and the Waste Water Treatment Area -- as shown in Figure 4-1. These wells were installed using the following procedures. The detailed procedures for well installation are described in the Quality Assurance Plan, RFI Proposal, Volume 2. First, a 10-inch diameter hole was advanced to the top of bedrock or to competent bedrock (as judged by the driller). An 8-inch diameter stainless steel casing was then grouted into the hole with cement/bentonite grout. Core samples of the bedrock were obtained using an NX-size core barrel. After coring, a 4-inch stainless steel well was installed inside the 8-inch casing. Two wells were completed with 10-foot screens and two wells were completed as open hole wells.

Boring logs for the piezometers and the bedrock wells are presented in Appendix D; well construction details are presented in Appendix F. Table 4-1 summarizes the elevation and depth data for all piezometers and wells at the facility, including information concerning end-of-boring depths and screened intervals.

The four bedrock wells were developed to remove remnants of drilling and to improve the communication between the formation and the well. Development techniques included surging and pumping with a submersible pump. The progress of well development was monitored by measuring the temperature, specific conductance, and turbidity of the pumped water. Well development was considered complete when turbidity, temperature, and/or specific conductance stabilized (i.e., four consecutive measurements were the same) or after one hour of development. Table 4-2 summarizes the development process for each bedrock well.

Slug tests were conducted on the piezometers and wells listed in Table 4-3 to estimate the hydraulic conductivity of the formation in the immediate vicinity of the screened intervals. (Hydraulic conductivity is defined as the rate of flow of water through a one foot by one foot square cross-section when the hydraulic gradient is equal to one). Both falling and rising head tests were conducted. In falling head tests, a slug cylinder is submerged in the well and the change in water level is recorded over time. In rising head tests, a slug cylinder is removed from the well and the change in water level again is recorded over time. An In-Situ SE1000B (Hermit) data logger was used to record water level changes, and field data were reduced using the technique described by Cooper, et al. (1967). A summary of slug test data reduction techniques and the slug test data obtained is presented in Appendix G. Slug tests are useful for characterizing aquifers that exhibit changes in head upon introduction or withdrawal of the slug that are slow enough to measure. If the changes in head are almost instantaneous (or too rapid to measure), the aquifer is too permeable for characterization using slug tests.

Ground water levels were measured in all piezometers and monitoring wells on 13 September 1990. The depth to the water level was measured relative to a point surveyed on the riser pipe of each well/piezometer using a Solinst Model 101 electronic water indicator. The surveyed point on each riser pipe had a known elevation. Measurements were taken to the nearest 0.01 foot. The water level depth measurement was subtracted from the elevation of the surveyed point on the riser pipe to obtain the elevation of the water surface at that location. Piezometric maps were produced by plotting and contouring water level elevations on a base map. Table 4-4 summarizes water elevation data for all five rounds of water level measurements at the site (26 April 1988, 7 June 1988, 19 April 1989, 1 June 1989, and 13 September 1990).

4.4 RESULTS OBTAINED

The results of the Phase IA hydrogeological investigation are presented in terms of:

- the definition of hydrostratigraphic units using boring logs;
- the potentiometric configuration of water in the bedrock and overburden aquifers; and
- the hydraulic conductivities of the bedrock and overburden aquifers.

These results are discussed more generally in Section 4.5.

4.4.1 Definition of Hydrostratigraphic Units Using Boring Logs.

Information obtained from stratigraphic soil borings was combined into three geologic cross-sections: A-A', B-B', and C-C' (Figures 3-2, 3-3, and 3-4). A generalized geologic sequence is evident: bedrock is overlain by till, which in turn is overlain by the unconsolidated overburden deposits. The overburden deposits include clayey silts, clays, sands, and fill.

The bedrock is composed primarily of metamorphosed sandstone, but metamorphosed siltstone and shale are also present in some cored intervals. Some of the cored intervals exhibit jointing or fracturing. The site stratigraphy indicates that the bedrock is overlain by till and/or clay and clayey silt in the overburden deposits at all locations. Therefore, the geological data suggest that the bedrock is a distinct hydrostratigraphic unit, separated from the overlying water table aquifer by till and/or clay and clayey silt.

The overburden deposits are composed of clays, clayey silts, sands, and fill. These deposits represent the second hydrostratigraphic unit, the water table aquifer. Stratigraphic boring data (Appendix D) indicate that there is considerable interfingering of clays and sands in the overburden deposits, producing a lack of stratigraphic continuity horizontally at any given depth. It is possible that the presence of clay layers produces semi-confined conditions at various depths and locations within the overburden deposits. Another source of variability in the overburden deposits is grain size. The grain size analyses of samples collected from the overburden sediments indicate that the samples are often poorly sorted (Figures 4-2A and 4-2B).

4.4.2 Potentiometric Configuration of Water in the Bedrock and Overburden Aquifers

In all four bedrock wells, the water elevation is higher than the top of bedrock (Table 4-4). In addition, the bedrock water elevations differ from the water table elevations. These two facts indicate that the bedrock aquifer is confined at the site. The geological data suggest that the confining layer may be the glacial till and/or clay and clayey silt beds in the overburden sediments.

Water elevations for the four bedrock wells are shown in Figure 4-3. The data were not contoured because there are two distinct contour configurations that are consistent with the data. The first possible configuration has contours that are roughly parallel to the river, and the downgradient direction is toward the river. This first configuration implies a hydraulic connection with the river. The second possible configuration has contours that contours that trend approximately northwest-southeast, and the downgradient direction is southwest. This second configuration implies no hydraulic connection with the river. Since the bedrock aquifer appears to be confined, it probably has no hydraulic connection with the river. Regardless, data from the four bedrock wells are insufficient to produce one potentiometric configuration for the bedrock aquifer. However, since there is no evidence of contamination in the bedrock aquifer at this time, defining the flow direction is not critical for the Phase IA investigation.

Two potentiometric maps were developed for the overburden deposits. The first map (Figure 4-4) plots data from piezometers completed approximately 5 feet above the till or bedrock (deep piezometers). The second map (Figure 4-5) plots data from piezometers completed approximately 5 feet below the water table (shallow piezometers).

The potentiometric map for the deep overburden piezometers/wells (Figure 4-4) has several notable features:

- o A comparatively steep potential gradient is present around bedrock high areas north of the Pawtuxet River (P-20D and P-19D). In contrast, the inferred contours north of the river show a less steep potential gradient between the bedrock high areas.

- o The piezometric surface in the deep part of the overburden aquifer in the Warwick Area is not well defined due to a lack of piezometers/wells penetrating to the bottom of the overburden deposits.

- o The ground water elevation at P-18D is lower than the elevation of the water surface in the Pawtuxet River. The cause of this anomalously low value is unknown. P-18D is screened across a zone for which there was no recovery in the stratigraphic-boring because of flowing sands. Therefore, the geology of the screened interval is unknown.

- Except at P-18D, the downgradient direction appears to be toward the Pawtuxet River.

Horizontal potential gradients in the deep part of the overburden deposits range from 0.02 to 0.10 (feet per horizontal foot), with the highest gradients located between the bedrock highs and the Pawtuxet River. This range of gradients was calculated using the inferred contours on the potentiometric map.

The potentiometric map for the shallow piezometers/wells (Figure 4-5) was based on more data and so is more detailed. Several aspects of this potentiometric map should be noted:

- Similar to the deep overburden potentiometric map, the shallow overburden potentiometric surface is comparatively steep around the bedrock high areas (P-20S, P-7S-A and P-7S-B). The contours approach a configuration parallel to the river between the bedrock high areas and the river. Between the bedrock high areas the potentiometric surface is less steep.

- The potentiometric contours are roughly parallel to the river in the Warwick Area.

- In the Production Area, the potentiometric surface becomes steep immediately adjacent to the bulkhead; this steep incline of the water table may be caused by flow downward to a discharge zone underneath the bottom edge of the bulkhead, an elevation of about -35 feet relative to MSL.

The horizontal potential gradient in the shallow overburden deposits in the Production Area ranges from 0.013 to 0.10 (feet per horizontal foot). The potential gradient is highest in the area near the bedrock high in the residential area (near P-20S, between the Production and Waste Water Treatment Areas). Horizontal potential gradients in the shallow overburden deposits range from 0.01 to 0.10 (feet per horizontal foot) in the Waste Water Treatment Area. In the Warwick Area (south of the river), horizontal potential gradients range from 0.02 to 0.066 (feet per horizontal foot).

The existence of nested pairs of piezometers or wells permits calculating vertical potential gradients by comparing water elevations in the two piezometers/wells. The elevation of the water in one piezometer/well is subtracted from the elevation in the other piezometer/well to obtain the change in head (ΔH). The ΔH is divided by the distance between the tops of the screens in the piezometers/wells (ΔL). The ratio of these values ($\Delta H/\Delta L$) is the vertical potential gradient. Figure 4-6 illustrates the vertical potential gradient in each nested pair of piezometers/wells at the facility.

Upward vertical potential gradients within the overburden aquifer range from 0.009 to 0.263 (feet per vertical foot). A few downward potential gradients were observed within the overburden deposits: 0.017 (feet per vertical foot) in P-1S/P1-D and 0.031 (feet per vertical foot) in MW-6S/P-18D. The downward potential gradient near the bulkhead in the Production Area may be caused by ground water flow downward underneath the bottom edge of the bulkhead. The cause of the downward gradient around MW-6S/P-18D is unknown; however, P-18D is screened across a zone for which there is no geological information. It is possible that P-18D is screened across clay, which would cause the potential gradient calculation to be inappropriate.

Upward vertical potential gradients from the bedrock aquifer to the overburden aquifer range from 0.013 to 0.648 feet per linear vertical foot. The vertical potential gradient data for MW-8S/RW-2 is merely an estimate because measurements on 13 September 1990 indicated that MW-8S was dry. However, the water elevation in MW-8S could be assumed to be less than 7 feet based on the potentiometric contours. Using this assumed elevation limit, the vertical gradient from RW-2 would be upward to the overburden aquifer by at least 0.214 (feet per vertical) foot. However, other reasonable assumptions could be made, so this vertical potential gradient should be regarded with caution. A downward vertical potential gradient of 0.033 (feet per vertical foot) was observed in the residential area at P-20D/RW-4. The cause of this downward vertical potential gradient is unknown.

4.4.3 Hydraulic Conductivities of the Bedrock and Overburden Aquifers.

Hydraulic conductivity values were generated using two techniques -- slug testing and laboratory testing. Slug testing yielded hydraulic conductivity values for screened intervals in the overburden aquifer. Laboratory values for hydraulic conductivity were measured on samples of clay and clayey silt collected from the overburden deposits. Therefore, hydraulic conductivity values from slug testing correspond to the higher-yielding parts of the overburden aquifer. In contrast, laboratory-generated hydraulic conductivities correspond to sediments that may function as aquitards or leaky confining layers.

Slug tests were conducted from 20 August to 22 August 1990 on all the piezometers and wells installed during the Phase IA investigation. The field data were reduced using a variety of techniques, but the Cooper technique (Cooper, et al., 1967) was used for most of the data reduction, with modifications based on Pandit and Miner (1986). Appendix G presents the slug test data and an explanation of the data reduction techniques used. Table 4-3 lists the tested piezometers/wells along with the test results. For some tests, data reduction was not possible. In other words, the test results could not be matched to any of the type curves. In the rising head test for P-17S, transducer movement or rapid recovery of the water level may have caused the lack of a match to a type curve. In both rising and falling head tests for P-22S, the data could not be matched to a type curve. A likely reason is that the length of the slug cylinder exceeded the height of the water column in the piezometer. At RW-2, very slow recovery of the water level during the rising and falling head tests may have caused the data to take a shape that precluded a match to a type curve. At P-18D, the cause of the variability in the test results is not known.

Hydraulic conductivities ranged from 0.1 to 1163 gallons per day per square foot (gpd/ft^2), a range that encompasses five orders of magnitude. Possible causes of this variation include natural variation in the formation and inappropriateness of slug testing to some ranges of hydraulic conductivity. In addition, slug testing is error-prone in rapidly recharging wells/piezometers; rapid recharging was observed in some of these slug tests. Theoretically, hydraulic conductivity values generated by the falling head tests should be close to the values generated by the rising head tests. Differences between the values generated by these two test methods suggest the magnitude of error variance in these tests. At best, the slug test values should be regarded as approximations of the aquifer properties.

Undisturbed samples collected from clay and clayey silt in the overburden deposits were analyzed for saturated hydraulic conductivity. Those results are presented in Table 4-5. The hydraulic conductivity values ranged from 8.8×10^{-7} to 4.0×10^{-4} cm/sec. Higher values (i.e., 10^{-4}) are not characteristic of clay or clayey silt (Fetter, 1980), and may represent silt or sand layers within the clay or clayey silt. The lower values are characteristic of clay and silt (Fetter, 1980), and indicate that the clay and clayey silt sediments may potentially function as aquitards.

Hydraulic conductivity also may be estimated using grain size distribution. Grain size analyses of clays, silts, and sands in the overburden deposits were plotted to produce grain size distribution curves; these curves are presented in Appendix E. The Hazen method of estimating hydraulic conductivity from grain size data (Freeze and Cherry, 1979) could not be applied to the grain size data from this investigation because the samples do not have uniform grain size. The Hazen method calculates hydraulic conductivity (k) as follows:

$$k = C(D_{10})^2$$

where D_{10} corresponds to the grain size distribution curve at the grain size value where 10% of the sample is finer-grained, and C is a constant with a value approximately equal to 100.

The Hazen method should be used only when D_{10} ranges from 0.1 to 3 mm, and when the uniformity coefficient (D_{60}/D_{10}) is 5 or less. (D_{60} is the grain size where 60% of the sample is finer-grained.) Dropping the D_{10} criterion and relaxing the uniformity coefficient criterion to 10 or less, hydraulic conductivity can be calculated for only 12 samples using the Hazen method (Table 4-6).

The Kozeny-Carmen method of calculating hydraulic conductivity (k) from grain size distribution curves (Freeze and Cherry, 1979) uses the following equation:

$$K=\left[\left(\frac{pg}{u}\right)\right]\left[\frac{n^3}{(1-n^2)}\right]\left[\left(\frac{D^2_{50}}{180}\right)\right]$$

In this equation, n is porosity, p is the density of water, g is the gravitational constant, and u is the viscosity of water. Table 4-6 shows the hydraulic conductivity values for each grain size analysis, assuming a porosity value assigned from published literature (Fetter, 1980). Laboratory-generated hydraulic conductivity values are also shown in Table 4-6.

4.5 DISCUSSION

The Phase IA hydrogeological investigation provided data indicating that the bedrock aquifer is at least partially confined by the till and/or overburden clay deposits. Evidence supporting this conclusion was provided by the hydrological and geological investigations as well. Considerable lateral variability of lithologies within the overburden deposits also was observed. Water elevation data for the bedrock aquifer are consistent with two different contour configurations, and thus two different conclusions about hydraulic connection to the Pawtuxet River. The first conclusion is that the bedrock aquifer is hydraulically connected to the river; the second is that they are not hydraulically connected. The second conclusion is consistent with a confined bedrock aquifer (as is suggested by other data). Therefore, the data suggest that the bedrock aquifer is not hydraulically connected to the Pawtuxet River.

Upward vertical potential gradients were most common in the nested pairs of piezometerrs/wells. However, some downward potential gradients within the overburden aquifer and down to the bedrock aquifer indicate the potential for downward flow. Likely, the potential downward flow in the Production Area can be attributed to the effect of the bulkhead; the cause of other downward vertical gradients is unknown. In all, the site stratigraphy is considerably more complex than was originally conceived. Further investigation is required in order to construct an adequate conceptual model of the site. In particular, the western end of the Warwick Area and the area north and west of the Waste Water Treatment Area are not adequately understood.

4.6 SUMMARY

The following preliminary conclusions can be drawn:

- Appropriate locations for future monitoring wells can be selected using the piezometric maps constructed from the Phase IA investigation. These maps indicate the downgradient direction relative to the positions of the Solid Waste Management Units (SWMUs), and permit locating the monitoring wells for each SWMU appropriately.

- The upper aquifer was characterized geologically by stratigraphic borings and geotechnical analyses, and was found to be considerably more complex than originally anticipated. Clays, silts, and sands are interbedded in the overburden deposits, and these lithologies are not always continuous laterally.

- The water elevation results for ground water in the bedrock aquifer indicate that there may or may not be hydraulic connection to the Pawtuxet River. However, if the bedrock aquifer is confined (as suggested by the data), hydraulic connection from the bedrock aquifer to the Pawtuxet River is unlikely.

- o Ground water flow directions and gradients were inferred from potentiometric maps of both the deeper part and the shallower part of the overburden aquifer. Ground water in both parts of the overburden aquifer appears to communicate with the river, so potential flow is toward the river. Horizontal potential gradients are high in the vicinity of the bedrock highs in the residential area and the Waste Water Treatment Area, and are lower between those bedrock highs. Vertical potential gradients are mostly upward, but a few downward potential gradients, both within the overburden aquifer as well as and downward to the bedrock aquifer, were observed. Near the bulkhead in the Production Area, downward vertical potential gradients within the overburden aquifer probably are artifacts of the bulkhead.

- o The seasonal variation in water levels was not documented in the Phase IA investigation because the investigation took place only during July and August 1990. Seasonal variations in ground water flow can be evaluated by comparing Phase IA water level measurements with previous water level measurements (Table 4-4). Only spring and summer are represented by water level measurement data. Most of the water levels measured in early spring are higher than those measured in late spring and summer. Relatively high water levels during the spring correspond to the rainy spring weather. Water levels recede during the late spring and summer, possibly in response to less rain and/or higher evapotranspiration.

- o Aquifer types and boundaries were evaluated. On the basis of both hydrological and geological data, the bedrock aquifer appears to be at least partially confined by till and/or clay overburden deposits. Potentiometric maps of the overburden aquifer indicate that the Pawtuxet River is a constant head boundary -- that is, the overburden aquifer drains to the river, and the elevation of the river surface is expected to remain constant over certain time scales. Because of numerous clay lenses and layers in the overburden deposits, partially confined conditions may exist at some depths and/or locations in the overburden aquifer.

- o Hydraulic conductivity of the bedrock and overburden aquifer was evaluated using slug tests. The hydraulic conductivity values are considered to be only approximations. Some data indicate that well recovery in the overburden materials is so rapid that slug testing is not an appropriate method for evaluating hydraulic conductivity at this site.

- o Overall, the Phase IA hydrogeological investigation provided the following new information: the bedrock aquifer appears to be confined, the potentiometric maps of the overburden aquifer were refined, and the vertical potential gradients are variable. However, information from the Phase IA hydrogeological investigation did not substantially affect the potentiometric configuration of the overburden aquifer in the vicinity of the SWMUs.

This section of the report concerned the hydrogeological investigation. The following section discusses the Phase IA hydrological investigation on the Pawtuxet River.

TABLE 4-1. SUMMARY OF PIEZOMETER AND MONITORING WELL CONSTRUCTION DETAILS
CIBA-GEIGY FACILITY
CRANSTON, RHODE ISLAND

Well/ Piezometer Number	Month/Year of Installation	Location Data		Elevation Data		Boring Data		Monitoring Well/Piezometer Data					
								Bottom of Monitoring Zone		Top of Monitoring Zone			
		Northing	Easting	Ground Surface	Top of Riser Pipe	Depth	Bottom Elevation	Depth	Elevation	Depth	Elevation	Length of Screen	Strata Monitored
P-1S	4/88	248838.37	523997.61	13.57	16.41	10.00	3.57	10.00	3.57	7.00	6.57	3.00	Fill
P-1D	4/88	248841.66	523999.27	13.59	16.33	49.5	-35.91	43.00	-29.41	40.00	-26.41	3.00	UD
P-2S	4/88	248685.97	523887.35	12.70	13.85	11.00	1.70	11.00	1.70	8.00	4.70	3.00	Fill
P-3S	4/88	248942.37	524128.06	14.30	15.45	11.50	2.80	11.50	2.80	8.50	5.80	3.00	Fill
P-4S	4/88	249042.14	523768.11	18.97	19.92	18.00	0.97	18.00	0.97	15.00	3.97	3.00	UD
P-5S	4/88	249030.59	523912.45	18.43	21.18	16.00	2.43	16.00	2.43	13.00	5.43	3.00	UD
P-6S	4/88	249111.64	524015.45	21.53	23.62	18.00	3.53	18.00	3.53	15.00	6.53	3.00	UD
P-6M	4/88	249091.36	524013.09	21.28	21.80	40.00	-18.72	40.00	-18.72	37.00	-15.72	3.00	UD
P-7S-A	4/88	249327.86	525323.32	14.73	16.26	9.00	5.73	9.00	5.73	6.00	8.73	3.00	UD
P-7S-B	4/88	249339.03	525320.60	14.63	15.68	14.00	0.63	14.00	0.63	11.00	3.63	3.00	UD
P-8S	4/88	249180.78	524849.59	15.04	16.21	11.50	3.54	11.50	3.54	8.50	6.54	3.00	UD
P-9S	4/88	249434.49	524997.15	14.88	16.10	12.00	2.88	12.00	2.88	9.00	5.88	3.00	UD
P-10S	4/88	249083.97	524985.17	12.50	14.13	12.00	0.50	12.00	0.50	9.00	3.50	3.00	UD
P-11S	4/88	249627.05	525025.11	14.50	17.95	10.00	4.50	10.00	4.50	7.00	7.50	3.00	NE
P-12S-A	4/88	249371.03	524763.23	14.21	15.29	12.00	2.21	12.00	2.21	9.00	5.21	3.00	NE
P-12S-B	4/88	249372.42	524766.81	14.21	15.32	26.50	-12.29	15.00	-0.79	12.00	2.21	3.00	NE
P-13S	4/88	249521.49	523773.93	23.82	26.99	15.00	8.82	14.00	9.82	11.00	12.82	3.00	NE
P-14S	4/88	249789.33	523852.83	23.74	24.18	13.00	10.74	13.00	10.74	10.00	13.74	3.00	UD
P-14D	4/88	249786.61	523846.62	23.68	23.95	58.50	-34.82	50.00	-26.32	47.00	-23.32	3.00	Till
P-15S	7/90	248665.87	524090.11	13.95	15.69	NA	NA	15.50	-1.55	12.50	1.45	3.00	UD

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TABLE 4-1. SUMMARY OF PIEZOMETER AND MONITORING WELL CONSTRUCTION DETAILS
CIBA-GEIGY FACILITY
CRANSTON, RHODE ISLAND

Well/ Piezometer Number	Month/Year of Installation	Location Data		Elevation Data		Boring Data		Monitoring Well/Piezometer Data					
								Bottom of Monitoring Zone		Top of Monitoring Zone			
		Northing	Easting	Ground Surface	Top of Riser Pipe	Depth	Bottom Elevation	Depth	Elevation	Depth	Elevation	Length of Screen	Strata Monitored
P-16S	7/90	248392.01	524030.95	14.26	16.29	NA	NA	15.50	-1.24	12.50	1.76	3.00	UD
P-17S	7/90	248521.88	524237.36	15.28	17.07	NA	NA	14.50	0.78	11.50	3.78	3.00	UD
P-18D	7/90	248993.61	525312.07	11.41	13.27	NA	NA	66.00	-54.59	63.00	-51.59	3.00	UD
P-19D	7/90	249349.16	525315.77	13.70	17.21	28.10	-14.40	28.10	-14.40	25.10	-11.40	3.00	UD
P-20S	7/90	249046.23	524252.46	24.60	24.02	NA	NA	22.00	2.60	19.00	5.60	3.00	UD
P-20D	7/90	249044.49	524256.97	24.61	24.30	NA	NA	26.00	-1.39	23.00	1.61	3.00	UD
P-21S	7/90	248901.93	524435.27	15.19	16.96	NA	NA	17.00	-1.81	14.00	1.19	3.00	UD
P-21D	7/90	248907.61	524443.58	14.04	15.75	42.00	-27.96	37.00	-22.96	34.00	-19.96	3.00	UD
P-22S	7/90	248494.29	524718.20	16.53	18.75	NA	NA	15.50	1.03	12.50	4.03	3.00	UD
P-22D	7/90	248485.76	524729.56	16.60	17.57	58.50	-41.90	58.00	-41.40	55.00	-38.40	3.00	UD
MW-1S	5/88	248849.44	523990.88	13.14	15.04	15.00	-1.86	13.00	0.14	3.00	10.14	10.00	Fill
MW-1D	5/88	248852.28	523985.86	13.93	16.28	50.00	-36.07	48.00	-34.07	38.00	-24.07	10.00	UD
MW-2S	5/88	248697.91	523904.81	12.56	14.46	20.00	-7.44	18.00	-5.44	8.00	4.56	10.00	Fill
MW-3S	5/88	248937.06	524119.09	14.57	16.61	20.00	-5.43	18.00	-3.43	8.00	6.57	10.00	UD/Fill
MW-4S	5/88	249005.42	523860.29	18.40	21.29	19.00	-0.60	16.00	2.40	6.00	12.40	10.00	UD/Fill
MW-5S	5/88	249738.80	523849.90	23.82	26.17	18.00	5.82	16.00	7.82	6.00	17.82	10.00	UD
MW-6S	5/88	248995.70	525283.37	11.91	14.04	30.00	-18.09	13.50	-1.59	3.50	8.41	10.00	UD
MW-7S	5/88	249307.92	525182.07	13.00	15.25	20.00	-7.00	18.00	-5.00	8.00	5.00	10.00	NE
MW-8S	5/88	249217.26	524936.35	15.13	17.57	30.00	-14.87	15.50	-0.37	5.50	9.63	10.00	UD/Fill

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TABLE 4-1. SUMMARY OF PIEZOMETER AND MONITORING WELL CONSTRUCTION DETAILS
CIBA-GEIGY FACILITY
CRANSTON, RHODE ISLAND

Well/ Piezometer Number	Month/Year of Installation	Location Data		Elevation Data		Boring Data		Monitoring Well/Piezometer Data					
								Bottom of Monitoring Zone		Top of Monitoring Zone			
		Northing	Easting	Ground Surface	Top of Riser Pipe	Depth	Bottom Elevation	Depth	Elevation	Depth	Elevation	Length of Screen	Strata Monitored
MW-9S	5/88	249576.85	524963.95	15.50	17.91	34.00	-18.50	13.00	2.50	3.00	12.50	10.00	UD/Fill
EP-1	--	249031.39	524120.01	21.64	22.90	--	--	--	--	--	--	--	--
EP-2	--	249529.36	523682.09	23.05	24.52	--	--	--	--	--	--	--	--
EP-5	--	248882.06	525340.61	12.52	15.84	--	--	--	--	--	--	--	--
EP-6	--	249162.41	525281.88	10.17	11.04	--	--	--	--	--	--	--	--
EP-7	--	248686.32	524961.77	14.09	14.37	--	--	--	--	--	--	--	--
EP-8	--	249192.54	523548.92	21.32	24.41	--	--	--	--	--	--	--	--
RW-1	8/90	248864.87	523989.83	14.94	16.52	59.70	-44.76	91.00	-76.06	81.00	-66.06	10.00	BR
RW-2	8/90	249219.69	524915.59	14.87	18.05	50.00	-35.13	70.00	-55.13	60.00	-45.13	10.00	BR
RW-3	8/90	248990.60	525291.75	11.87	13.49	60.00	-48.13	82.00	-70.13	72.00	-60.13	10.00	BR
RW-4	8/90	249039.74	524255.17	24.08	23.79	33.50	9.42	50.00	-25.92	40.00	-15.92	10.00	BR

NOTES:

1. Elevations and depths are reported in feet; elevations are referenced to Mean Sea Level.
2. -- = Information Not Available
3. UD = Unconsolidated Deposits
4. BR = Bedrock
5. NE = Not Evaluated
6. Elevation data based on surveys by Waterman Engineering Co. of East Providence, RI, Louis Federici Associates of Providence, RI, and Woodward-Clyde Consultants of Wayne, NJ.

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TABLE 4-2. PHASE IA BEDROCK WELL DEVELOPMENT DATA
CIBA-GEIGY CRANSTON, RHODE ISLAND FACILITY

Bedrock Well	Date	Start Time	Completion Time	Development Method	Turbidity*	Temperature*	Conductivity*
RW-1	8/7/90	9:40	13:35	Submersible Pump/Surge	15	17.0°C	11 μmhos/cm
RW-2	8/3/90	11:26	11:46	Submersible Pump/Surge	NM	18.5°C	190 μmhos/cm
RW-3	8/3/90	16:05	17:55	Submersible Pump/Surge	NM	19.0°C	116 μmhos/cm
RW-4	8/6/90	14:40	15:43	Submersible Pump	NM	19.5°C	195 μmhos/cm

NM = not measured
* = stabilized readings
μmhos/cm = micromhos per centimeter

TABLE 4-3. SUMMARY OF SLUG TEST DATA
CIBA-GEIGY FACILITY
CRANSTON, RI

Well ID	Test No.	Falling or Rising Head Test	Data Reduction Technique	TC (gpd/ft)	TAQ (gpd/ft)	K (cm/sec)
P-15S	P15S	Falling	Black (1978)	NA	NA	1.1 E-2
	P15SA	Rising	Black (1978)	Na	NA	1.1 E-2
P-16S	P16S	Falling	Black (1978)	NA	NA	1.1 E-2
	P16SA	Rising	Black (1978)	NA	NA	1.1 E-2
P-17S	P17S	Falling	Bouwer & Rice (1976)	NA	NA	1.7 E-3
	P17SA	Rising	Unable to Reduce Data*			
P-18D	P18D	Falling	Unable to Reduce Data*			
	P18DA	Rising	Unable to Reduce Data*			
P-19D	P19D	Falling	Cooper et al (1967)	28	240	4.3 E-4
	P19DA	Rising	Cooper et al (1967)	4	385	6.9 E-4
P-20S	P20SR	Falling	Cooper et al (1967)	37	NA	5.7 E-4
	P20SA	Rising	Cooper et al (1967)	65	NA	1.0 E-3
P-20D	P20D	Falling	Cooper et al (1967)	3	8	4.2 E-5
	P20DA	Rising	Cooper et al (1967)	6	18	1.0 E-4
P-21S	P21S	Falling	Cooper et al (1967)	1	NA	1.9 E-5
	P21SA	Rising	Cooper et al (1967)	1	NA	1.5 E-5
P-21D	P21D	Falling	Cooper et al (1967)	543	6421	8.5 E-3
	P21DA	Rising	Cooper et al (1967)	2779	32,483	4.3 E-2
P-22S	P22S	Falling	Unable to Reduce Data*			
	P22SA	Rising	Unable to Reduce Data*			

TABLE 4-3. SUMMARY OF SLUG TEST DATA (continued)
CIBA-GEIGY FACILITY
CRANSTON, RHODE ISLAND

Well ID	Test No.	Falling or Rising Head Test	Data Reduction Technique	TC (gpd/ft)	TAQ (gpd/ft)	K (cm/sec)
P-22D	P22D	Falling	Cooper et al (1967)	3490	59,960	5.4 E-2
	P22DA	Rising	Cooper et al (1967)	510	88,829	8.0 E-2
RW-1	RW1	Falling	Cooper et al (1967)	26	NA	1.0 E-4
	RW1A	Rising	Cooper et al (1967)	45	NA	1.7 E-4
RW-2	RW2	Falling	Unable to Reduce Data*			
	RW2A	Rising	Unable to Reduce Data*			
RW-3	RW3	Falling	Cooper et al (1967)	4	NA	1.7 E-5
	RW3A	Rising	Cooper et al (1967)	1	NA	4.3 E-6
RW-4	RW4	Falling	Cooper et al (1967)	1292	NA	5.0 E-3
	RW4A	Rising	Cooper et al (1967)	840	NA	3.3 E-3

NOTES:
TC = Transmissivity across the screened length of the well per Cooper, et al. (1967) in gallons per day/foot.
TAQ = Transmissivity across the saturated thickness of the aquifer in gallons per day/foot.
K = Horizontal Hydraulic Conductivity (in centimeters per second). Reported in scientific rotation (i.e., 3.3 E-3 = 0.0033).
* = See text for explanation.

TABLE 4-4. SUMMARY OF GROUND WATER ELEVATION DATA
CIBA-GEIGY FACILITY
CRANSTON, RHODE ISLAND

Piezometer/ Well No.	Water Level Elevation 26 April 1988	Water Level Elevation 7 June 1988	Water Level Elevation 19 April 1989	Water Level Elevation 1 June 1989	Water Level Elevation 13 September 1990
P-1S	8.88	NM	10.16	9.57	8.78
P-1D	8.28	NM	9.48	8.68	8.23
P-2S	8.01	NM	9.34	8.54	8.26
P-3S	7.43	NM	8.28	6.66	7.46
P-4S	11.79	NM	12.81	12.11	11.32
P-5S	11.22	NM	12.06	11.51	10.64
P-6S	11.36	NM	12.34	11.74	10.63
P-6M	11.51	NM	12.47	11.93	11.04
P-7S-A	6.25	NM	7.44	6.75	10.70
P-7S-B	6.24	NM	7.39	6.76	10.38
P-8S	6.13	NM	7.12	6.65	6.56
P-9S	7.86	NM	9.34	8.40	9.11
P-10S	6.25	NM	7.20	6.69	6.54
P-11S	11.79	NM	12.33	12.16	11.86
P-12S-A	7.80	NM	9.12	8.23	7.64
P-12S-B	8.69	NM	10.19	10.20	8.43
P-13S	13.68	NM	14.73	NM	14.08
P-14S	14.91	NM	15.85	15.39	14.25
P-14D	15.10	NM	16.20	15.79	14.57

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Done by KM; checked by MD

TABLE 4-4. SUMMARY OF GROUND WATER ELEVATION DATA
CIBA-GEIGY FACILITY
CRANSTON, RHODE ISLAND

Piezometer/ Well No.	Water Level Elevation 26 April 1988	Water Level Elevation 7 June 1988	Water Level Elevation 19 April 1989	Water Level Elevation 1 June 1989	Water Level Elevation 13 September 1990
P-15S*	NI	NI	NI	NI	6.84
P-16S*	NI	NI	NI	NI	7.09
P-17S*	NI	NI	NI	NI	9.35
P-18D*	NI	NI	NI	NI	4.93
P-19D*	NI	NI	NI	NI	13.07
P-20D*	NI	NI	NI	NI	10.17
P-20S*	NI	NI	NI	NI	10.81
P-21S*	NI	NI	NI	NI	7.01
P-21D*	NI	NI	NI	NI	10.16
P-22S*	NI	NI	NI	NI	9.21
P-22D*	NI	NI	NI	NI	11.18
EP-1	10.48	NM	11.41	10.86	10.16
EP-2	13.79	NM	14.82	14.23	11.96
EP-5	7.49	NM	8.83	8.45	7.48
EP-6	6.11	NM	7.33	NM	6.68
EP-7	7.66	NM	9.91	9.16	"Dry" **
EP-8	13.22	NM	14.27	13.60	NM

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Done by KM; checked by MD

TABLE 4-4. SUMMARY OF GROUND WATER ELEVATION DATA CIBA-GEIGY FACILITY CRANSTON, RHODE ISLAND					
Piezometer/ Well No.	Water Level Elevation 26 April 1988	Water Level Elevation 7 June 1988	Water Level Elevation 19 April 1989	Water Level Elevation 1 June 1989	Water Level Elevation 13 September 1990
MW-1S	NM	9.57	10.82	9.99	NM
MW-1D	NM	9.97	9.74	9.13	8.74
MW-2S	NM	8.70	10.06	9.35	8.53
MW-3S	NM	8.27	9.10	8.53	8.20
MW-4S	NM	11.58	12.27	11.87	NM
MW-5S	NM	14.85	15.80	15.39	14.16
MW-6S	NM	6.55	7.52	6.86	6.76
MW-7S	NM	6.97	8.03	7.33	7.14
MW-8S	NM	6.07	6.95	6.50	"Dry" **
MW-9S	NM	11.33	12.52	11.26	11.54
RW-1*	NI	NI	NI	NI	8.76
RW-2*	NI	NI	NI	NI	11.33
RW-3*	NI	NI	NI	NI	10.46
RW-4*	NI	NI	NI	NI	9.59

NOTES:

1. Elevations are reported in feet and referenced to Mean Sea Level.
2. NM = not measured; NI = not installed at that time.
3. The Pawtuxet River elevation was recorded at the location of the railroad bridge on 19 April 1989, 1 June 1989, and 13 September 1990. The elevations were 6.96, 6.46, 6.70, and 6.50, respectively.

* Installed during Phase IA

** The measurement indicates that the well/piezometer is dry, but this result is not likely based on other considerations. Field error is likely.

TABLE 4-5. GEOTECHNICAL RESULTS FOR UNDISTURBED SOIL SAMPLES
CIBA-GEIGY FACILITY
CRANSTON, RHODE ISLAND

SAMPLE ID	SAMPLE DEPTH (ft)	DRY BULK DENSITY (pcf)	POROSITY (%)	HYDRAULIC CONDUCTIVITY (cm/sec) *
P19D-ST-1	14-16	98.3	34.3	5.0 E-6
P19D-ST-2	20-22	80.8	46.0	1.6 E-6
P21D-ST1	16-18	98.4	36.9	8.8 E-7
P21D-ST-2	30-32	87.2	41.8	4.0 E-4
P22D-ST1	24.5-26.5	96.0	35.9	2.1 E-6
P22D-ST2	34.5-36.5	88.1	41.1	1.4 E-5
RW-1-ST-1	45-47	96.2	35.7	2.0 E-5
RW-2-ST-1	20-22	88.8	40.7	1.3 E-5
RW-3-ST-1	20-22	110.2	26.4	2.3 E-4
RW-3-ST-2	28-30	91.5	38.9	1.7 E-6
RW-4-ST-1	24-26	107.0	31.4	8.5 E-7

pcf = pounds per cubic foot
* Hydraulic conductivity values are written in scientific notation (i.e., 2.3 E-4 = 0.00023).

TABLE 4-6. CALCULATION OF HYDRAULIC CONDUCTIVITY FROM GRAIN SIZE DISTRIBUTION CURVES. (1)

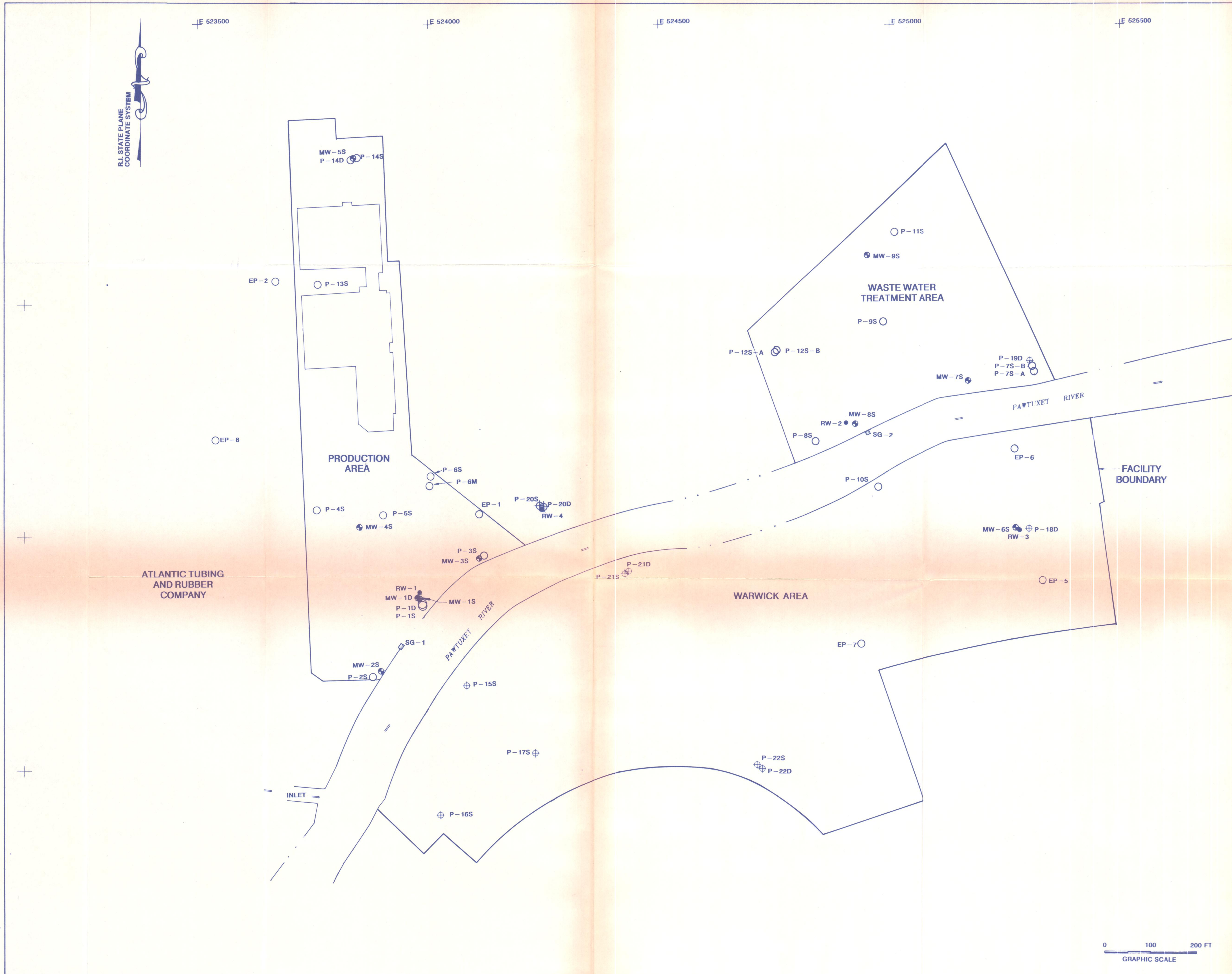
CIBA-GEIGY FACILITY

CRANSTON, RHODE ISLAND

GRAIN SIZE SAMPLES FROM THE SATURATED ZONE

SAMPLE ID	GRAIN SIZE CLASSIFICATION AT D50 (2)	D10 (mm) (3)	D50 (mm) (3)	D60 (mm) (3)	D90 (mm) (3)	D60/D10 (uniformity ratio)	ASSIGNED POROSITY from Fetter, 1980) (4	HYDRAULIC CONDUCTIVITY BY HAZEN METHOD (cm/sec) (5)	HYDRAULIC CONDUCTIVITY BY KOZENY-CARMEN METHOD (cm/sec) (5)	HYDRAULIC CONDUCTIVITY BY LABORATORY METHOD (cm/sec) (5)
P22DSS5	SAND	0.001	0.094	0.11	0.2	110.0	0.275		2.1E-01	
P21DSS15	SAND	0.056	0.18	0.24	0.67	4.3	0.275	3.1E-03	7.8E-01	
RW4S9	SAND	0.013	0.15	0.19	0.55	14.6	0.275		5.4E-01	
RW3S7	SAND	0.14	0.89	1.2	3.1	8.6	0.275	2.0E-02	1.9E01	
RW1SS13-15	SAND	0.093	0.74	0.92	2	9.9	0.275	8.6E-03	1.3E01	
RW1SS8	SAND	0.068	0.49	0.72	2.7	10.6	0.275		5.8E00	
P21DSS18	SAND	0.001	1.3	1.6	4.9	1600.0	0.275		4.1E01	
P19DSS67A	SAND	0.13	1.4	1.8	4.8	13.8	0.275		4.7E01	
P19DSS4	SAND	0.089	0.59	0.86	4.3	9.7	0.275	7.9E-03	8.4E00	
RW3ST1	SAND	0.001	0.08	0.096	0.19	96.0	0.275		1.5E-01	
RW3S4	SAND	0.0033	0.14	0.17	0.44	51.5	0.275		4.7E-01	
RW2S22	SAND	0.001	0.17	0.23	0.68	230.0	0.275		7.0E-01	
RW1SS24	SAND	0.001	0.95	2.2	4.9	2200.0	0.275		2.2E01	
RW1SS20	SAND	0.0033	0.096	0.14	0.43	42.4	0.275		2.2E-01	
P21DST2	SAND	0.067	0.2	0.24	0.38	3.6	0.275	4.5E-03	9.7E-01	
P19DST1	SILT	0.001	0.0058	0.0089	0.05	8.9	0.425	1.0E-06	4.8E-03	5.0E-06
RW2S15	SILT	0.0023	0.036	0.048	0.22	20.9	0.425		1.8E-01	
RW4ST1	SILT	0.001	0.007	0.013	0.44	13.0	0.425		6.9E-03	8.5E-07
RW3ST2	SILT	0.001	0.02	0.029	0.066	29.0	0.425		5.7E-02	1.7E-06
RW2ST1	SILT	0.001	0.0076	0.012	0.05	12.0	0.425		8.2E-03	1.3E-05
RW1ST1	SILT	0.001	0.005	0.0073	0.027	7.3	0.425	1.0E-06	3.5E-03	2.0E-05
P21DST1	SILT	0.001	0.0058	0.0089	0.043	8.9	0.425	1.0E-06	4.8E-03	8.6E-07
P22DST2	SILT	0.001	0.0057	0.008	0.013	8.0	0.425	1.0E-06	4.6E-03	1.4E-05
P19DST2	SILT	0.001	0.0058	0.0078	0.026	7.8	0.425	1.0E-06	4.8E-03	1.6E-06
P22DST1	CLAY	0.001	0.0033	0.0054	0.027	5.4	0.465	1.0E-06	2.3E-03	2.1E-06

Done by MD, checked by RH



LEGEND

P–5S	EXISTING PIEZOMETER
MW–6S	EXISTING MONITORING WELL
P–22S	PIEZOMETER INSTALLED DURING PHASE IA OF THE RCRA FACILITY INVESTIGATION
RW–1	BEDROCK WELL INSTALLED DURING PHASE IA OF THE RCRA FACILITY INVESTIGATION
SG–1	STREAM GAGE
EP–1	EXISTING PIEZOMETER (PRELIMINARY INVESTIGATION)

NOTE:
MONITORING WELL AND PIEZOMETER LOCATIONS BASED ON SURVEY BY LOUIS FEDERICI & ASSOCIATES OF PROVIDENCE, RHODE ISLAND

MONITORING WELL AND PIEZOMETER LOCATIONS
CIBA–GEIGY FACILITY
CRANSTON, RHODE ISLAND

WOODWARD-CLYDE CONSULTANTS
CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS
WAYNE, NEW JERSEY

DR. BY	MG	SCALE	1: 1200	PROJ. NO.	87X4660
CK. BY	CWT	DATE	SEPT 21 1990	FIG. NO.	4–1

TABLE 4-6. CALCULATION OF HYDRAULIC CONDUCTIVITY FROM GRAIN SIZE DISTRIBUTION CURVES. (1)										
CIBA-GEIGY FACILITY										
CRANSTON, RHODE ISLAND										
GRAIN SIZE SAMPLES FROM THE UNSATURATED ZONE										
SAMPLE ID	GRAIN SIZE CLASSIFICATION AT D50 (2)	D10 (mm) (3)	D50 (mm) (3)	D60 (mm) (3)	D90 (mm) (3)	D60/D10 (uniformity ratio)	ASSIGNED POROSITY from Fetter, 1980) (4	HYDRAULIC CONDUCTIVITY BY HAZEN METHOD (cm/sec) (5)	HYDRAULIC CONDUCTIVITY BY KOZENY-CARMEN METHOD (cm/sec) (5)	HYDRAULIC CONDUCTIVITY BY LABORATORY METHOD (cm/sec) (5)
P22DSS2	SAND	0.001	0.022	0.044	0.15	44.0	0.275		1.2E-02	
P22DSS3B	SAND	0.16	1	1.5	2	9.4	0.275	2.6E-02	2.4E01	
RW4S5	SAND	0.001	0.18	0.25	0.79	250.0	0.275		7.8E-01	
RW2SB2	SAND	0.081	0.73	1.2	4.8	14.8	0.275		1.3E01	
P21DSS1	SAND	0.072	0.89	1.6	4.8	22.2	0.275		1.9E01	
P21DSS5	SAND	0.003	0.15	0.15	0.76	60.0	0.275		5.4E-01	
P19DSS1-2	SAND	0.0035	0.14	0.17	0.42	48.6	0.275		4.7E-01	

(1) Calculation methods used include the Hazen and the Kozeny-Carmen methods (Freeze and Cherry, 1979). Laboratory values are also shown. See text for equations.

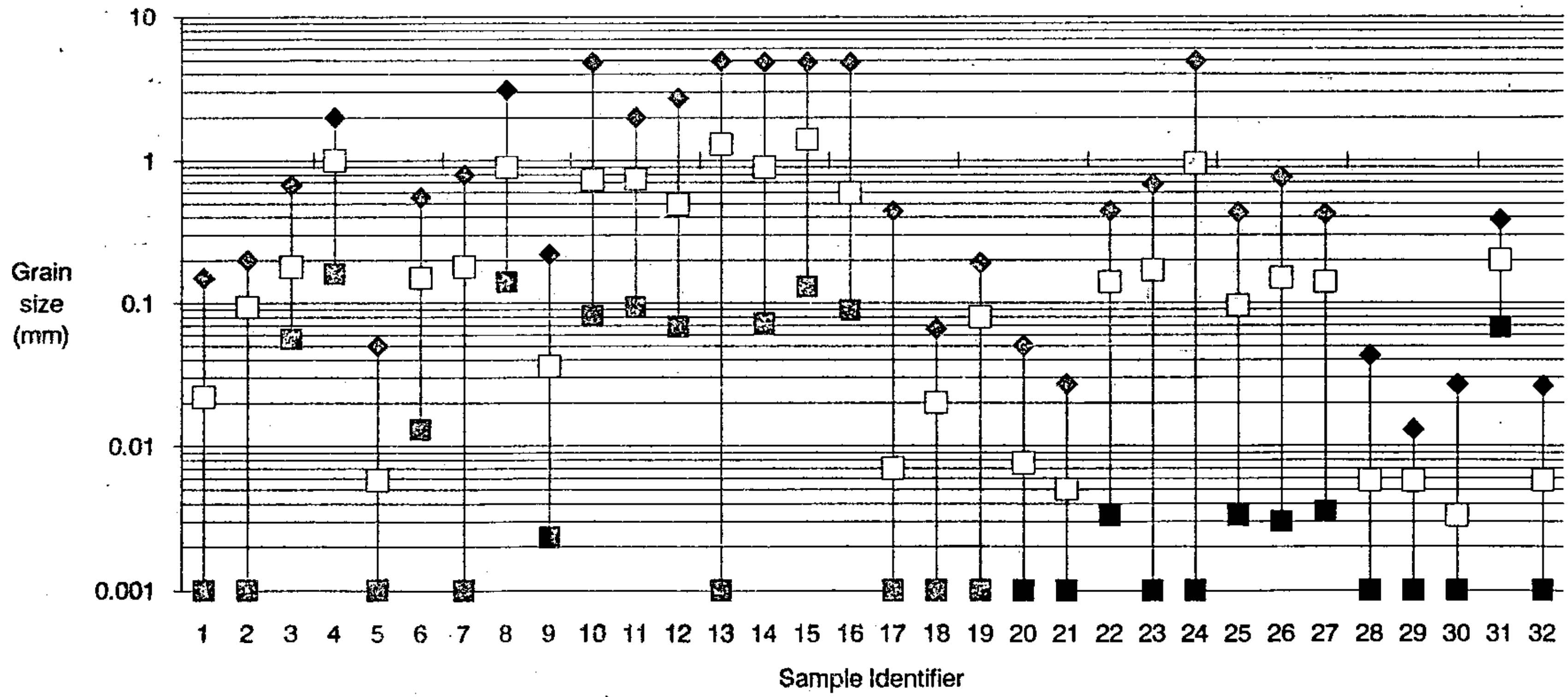
(2) Classification used to characterize the median grain size (D50) of the sample is Wentworth-Udden (Leeder, 1982).

(3) D10, D50, D60, and D90 denote the grain size values from the distribution curves for which 10%, 50%, 60%, and 90% of the sample, respectively, is finer-grained.

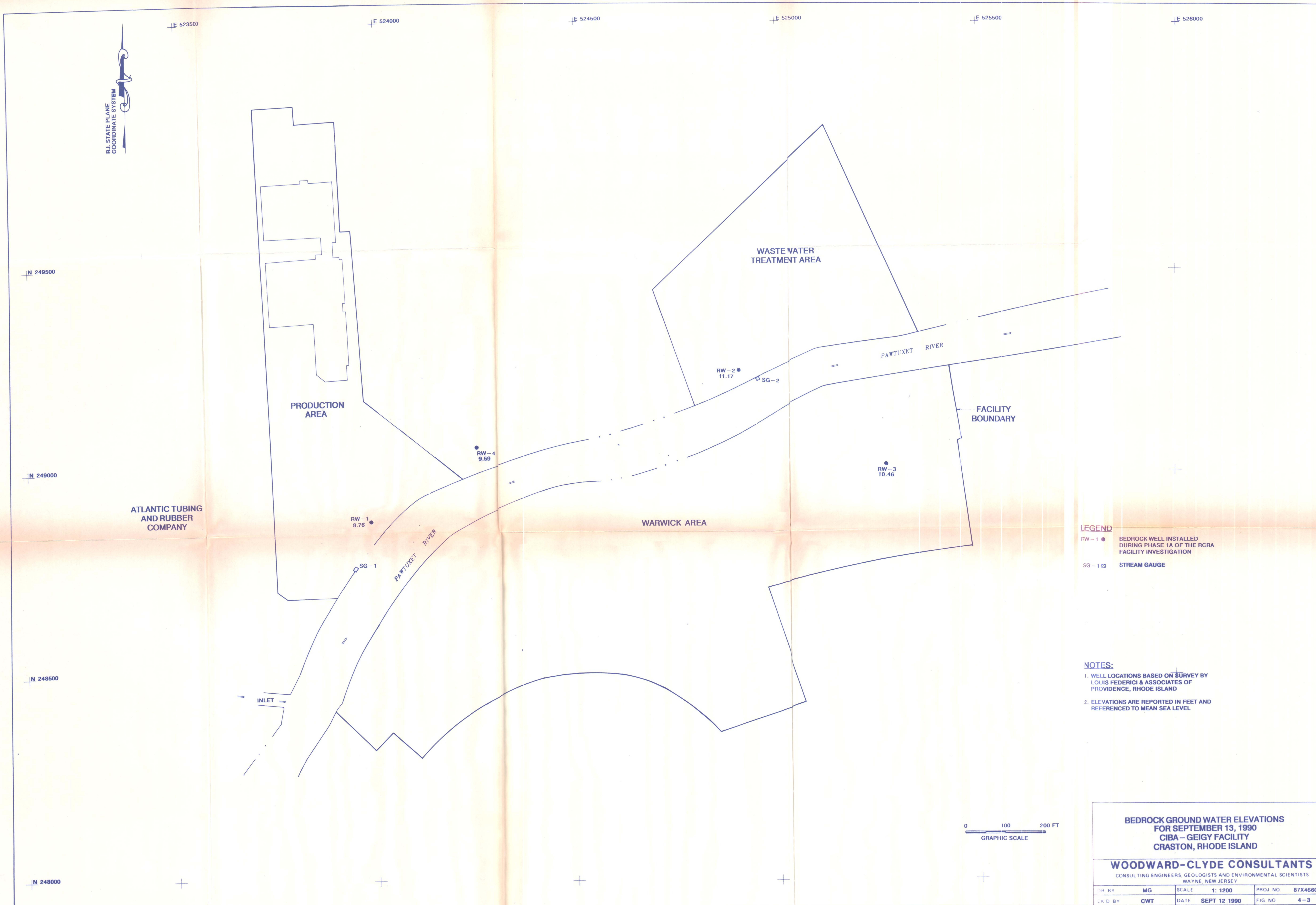
(4) Porosity values were selected from a table of typical porosity values for unconsolidated sand, silt, and clay (Fetter, 1980).

(5) Hydraulic conductivity values are reported in scientific notation: 1.0 E-03 = 0.001cm/sec.

Figure 4-2A. The D10, D50, and D90 of overburden samples collected from soil borings, CIBA-GEIGY, Cranston, RI, plotted on a logarithmic scale.



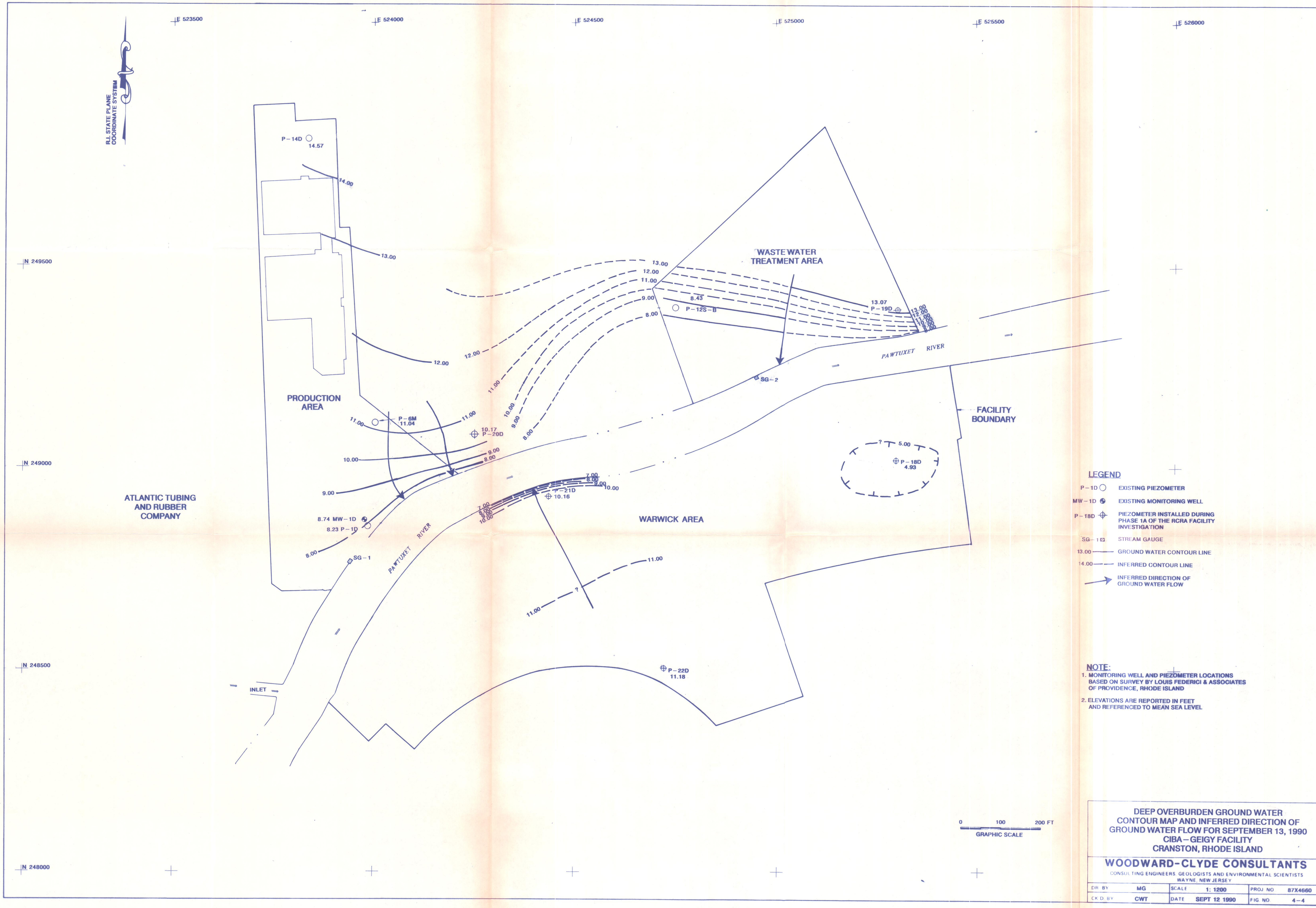
Done by MD, checked by RH

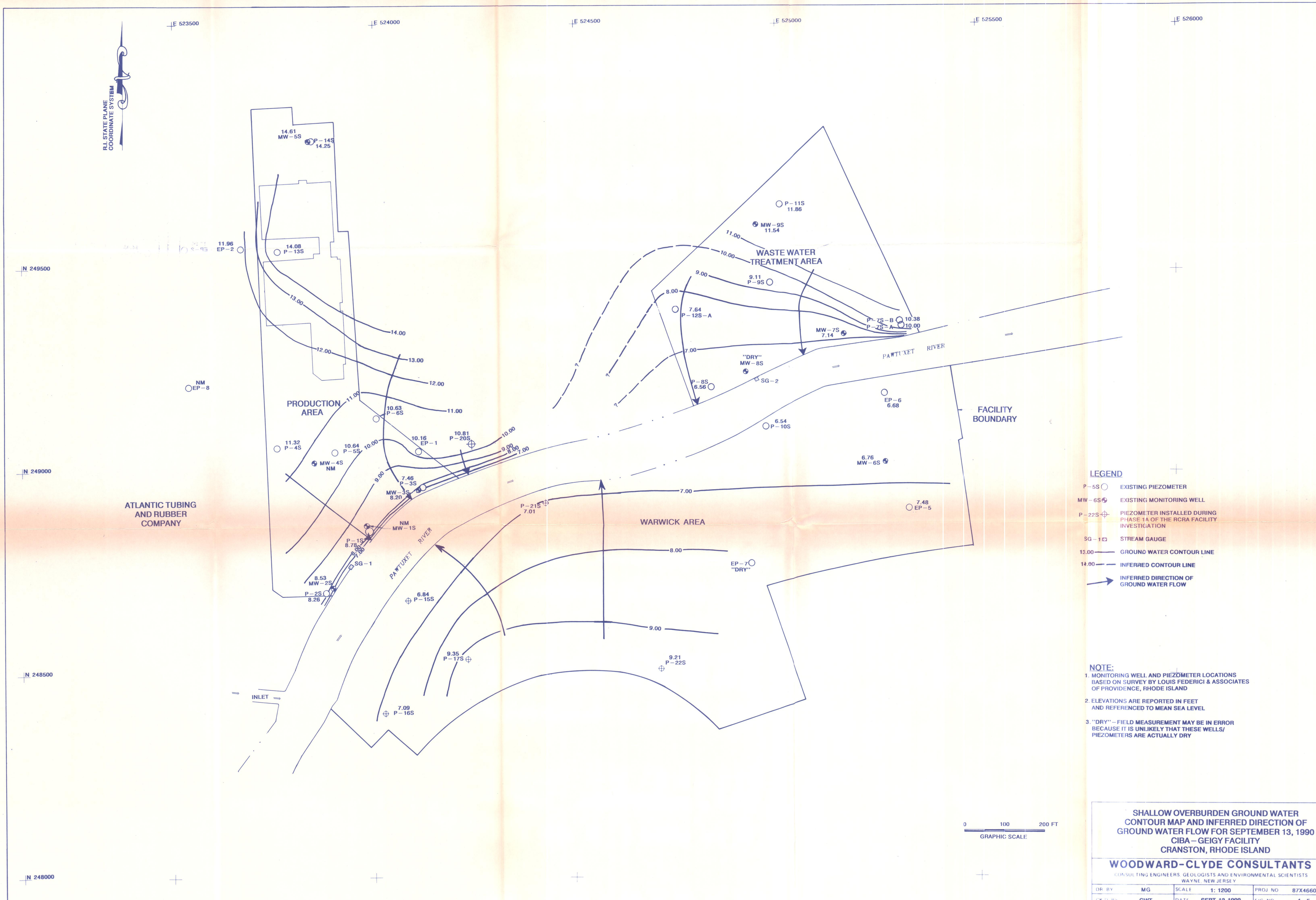


BEDROCK GROUND WATER ELEVATIONS FOR SEPTEMBER 13, 1990
CIBA-GEIGY FACILITY
CRASTON, RHODE ISLAND

WOODWARD-CLYDE CONSULTANTS
CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS
WAYNE, NEW JERSEY

DR. BY	MG	SCALE	1: 1200	PROJ NO	87X4660
CKD BY	CWT	DATE	SEPT 12 1990	FIG NO	4-3


E 523500
E 524000
E 524500
E 525000
E 525500
E 526000
N 249500
N 249000
N 248500
N 248000
R.I. STATE PLANE COORDINATE SYSTEM
P – 14D
14.57
14.00
13.00
12.00
11.00
10.00
9.00
8.00
13.00
12.00
11.00
9.00
8.00
8.43
P – 12S – B
13.07
P – 19D
WASTE WATER TREATMENT AREA
PRODUCTION AREA
P – 6M
11.04
10.17
P – 20D
PAWTUXET RIVER
SG – 2
FACILITY BOUNDARY
5.00
P – 18D
4.93
7.00
8.00
9.00
10.00
P – 21D
10.16
ATLANTIC TUBING AND RUBBER COMPANY
8.74 MW – 1D
8.23 P – 1D
SG – 1
WARWICK AREA
11.00
INLET
P – 22D
11.18
LEGEND
P – 1D EXISTING PIEZOMETER
MW – 1D EXISTING MONITORING WELL
P – 18D PIEZOMETER INSTALLED DURING PHASE 1A OF THE RCRA FACILITY INVESTIGATION
SG – 1 STREAM GAUGE
13.00 GROUND WATER CONTOUR LINE
14.00 INFERRED CONTOUR LINE
INFERRED DIRECTION OF GROUND WATER FLOW
NOTE:
1. MONITORING WELL AND PIEZOMETER LOCATIONS BASED ON SURVEY BY LOUIS FEDERICI & ASSOCIATES OF PROVIDENCE, RHODE ISLAND
2. ELEVATIONS ARE REPORTED IN FEET AND REFERENCED TO MEAN SEA LEVEL
0 100 200 FT
GRAPHIC SCALE
DEEP OVERBURDEN GROUND WATER CONTOUR MAP AND INFERRED DIRECTION OF GROUND WATER FLOW FOR SEPTEMBER 13, 1990
CIBA – GEIGY FACILITY
CRANSTON, RHODE ISLAND
WOODWARD-CLYDE CONSULTANTS
CONSULTING ENGINEERS GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS
WAYNE, NEW JERSEY
DR. BY MG
SCALE 1: 1200
PROJ. NO. 87X4660
CK'D. BY CWT
DATE SEPT 12 1990
FIG. NO. 4 – 4



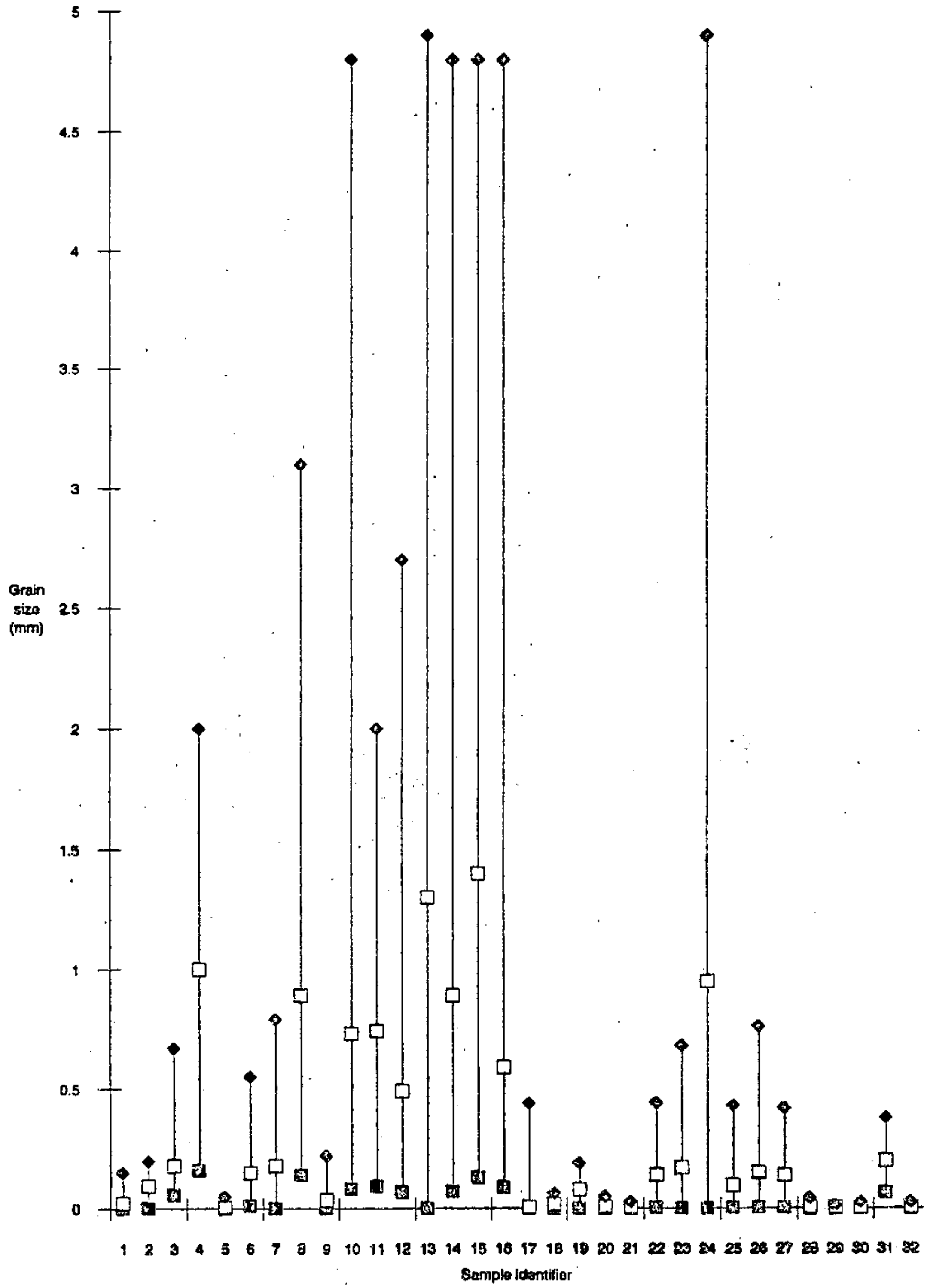
R.I. STATE PLANE COORDINATE SYSTEM
E 523500
E 524000
E 524500
E 525000
E 525500
E 526000
N 249500
N 249000
N 248500
N 248000
14.61 MW-5S
P-14S 14.25
11.96 EP-2
14.08 P-13S
NM EP-8
PRODUCTION AREA
11.32 P-4S
10.64 P-5S
MW-4S NM
10.63 P-6S
10.16 EP-1
10.81 P-20S
7.46 P-3S
MW-3S 8.20
NM MW-1S
P-1S 8.78
SG-1
8.53 MW-2S
P-2S 8.26
ATLANTIC TUBING AND RUBBER COMPANY
P-11S 11.86
MW-9S 11.54
WASTE WATER TREATMENT AREA
9.11 P-9S
7.64 P-12S-A
P-7S-B 10.38
P-7S-A 10.00
MW-7S 7.14
"DRY" MW-8S
SG-2
P-8S 6.56
PAWTUXET RIVER
EP-6 6.68
6.54 P-10S
6.76 MW-6S
FACILITY BOUNDARY
P-21S 7.01
WARWICK AREA
7.48 EP-5
EP-7 "DRY"
6.84 P-15S
9.35 P-17S
9.21 P-22S
7.09 P-16S
INLET
14.00
13.00
12.00
11.00
10.00
9.00
8.00
7.00
LEGEND
P-5S EXISTING PIEZOMETER
MW-6S EXISTING MONITORING WELL
P-22S PIEZOMETER INSTALLED DURING PHASE 1A OF THE RCRA FACILITY INVESTIGATION
SG-1 STREAM GAUGE
13.00 GROUND WATER CONTOUR LINE
14.00 INFERRED CONTOUR LINE
INFERRED DIRECTION OF GROUND WATER FLOW
NOTE:
1. MONITORING WELL AND PIEZOMETER LOCATIONS BASED ON SURVEY BY LOUIS FEDERICI & ASSOCIATES OF PROVIDENCE, RHODE ISLAND
2. ELEVATIONS ARE REPORTED IN FEET AND REFERENCED TO MEAN SEA LEVEL
3. "DRY" - FIELD MEASUREMENT MAY BE IN ERROR BECAUSE IT IS UNLIKELY THAT THESE WELLS/ PIEZOMETERS ARE ACTUALLY DRY
0 100 200 FT
GRAPHIC SCALE
SHALLOW OVERBURDEN GROUND WATER CONTOUR MAP AND INFERRED DIRECTION OF GROUND WATER FLOW FOR SEPTEMBER 13, 1990
CIBA-GEIGY FACILITY
CRANSTON, RHODE ISLAND
WOODWARD-CLYDE CONSULTANTS
CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS
WAYNE, NEW JERSEY
DR. BY MG
SCALE 1: 1200
PROJ. NO. 87X4660
CK'D. BY CWT
DATE SEPT 12 1990
FIG. NO. 4-5

HEAD DISTRIBUTION AND VERTICAL POTENTIAL GRADIENTS IN NESTED PIEZOMETERS/WELLS
CIBA-GEIGY FACILITY
CRANSTON, RHODE ISLAND

WOODWARD-CLYDE CONSULTANTS
CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS
WAYNE, NEW JERSEY

DR. BY:	BAS	SCALE:	AS SHOWN	PROJ. NO.:	87X4660
CK'D. BY:	CWT	DATE:	10 OCT 1990	FIG. NO.:	4-6

Figure 4-2B. The D10, D50, and D90 of overburden samples collected from soil borings, CIBA-GEIGY, Cranston, RI, plotted on a linear scale.



Done by MD, checked by RH

Section Five

SECTION 5
HYDROLOGICAL INVESTIGATION

5.1 OVERVIEW

A hydrological investigation of the Pawtuxet River was undertaken along the reach bordered by the CIBA-GEIGY Cranston facility (hereafter called the "facility reach"). The facility reach extends from just upstream of the Bellefont Pond drainage outlet to just downstream of the Warwick Avenue Bridge (Figure 5-1). Chapters 1 and 3 in Volume 1 of the RFI Proposal contain detailed descriptions of the Pawtuxet River and its watershed, based on information obtained from the United States Geological Survey (USGS) and from CIBA-GEIGY files.

The RFI Proposal included a geographical description of the river and its watershed, a discussion of flow statistics for the river at the USGS gauge at Cranston, a review of estimated sedimentation rates, and a review of the Rhode Island state classification of the Pawtuxet River. All the information about the river in the RFI Proposal was obtained by searching the literature. For this reason, the Phase IA hydrological investigation included direct measurement or evaluation of the river flow, bathymetry, and sediments along the facility reach. For example, the flow and sedimentation of the Pawtuxet River along the facility reach were evaluated using the data gathered in this investigation. Water discharge data were compared to USGS data for the Pawtuxet River. Sedimentation patterns were evaluated using bathymetry, suspended sediment sampling, and by calculating the flow regime for the flow conditions observed during the investigation.

5.2 INTRODUCTION AND OBJECTIVES

The hydrological investigation of the Pawtuxet River was conducted in accordance with the Facility Investigation Work Plan in Volume 1 of the RFI proposal. The overall goal of the hydrological investigation was to evaluate the physicochemical characteristics of the river with respect to storage and/or transport of constituents of concern. To accomplish this goal, the following activities were undertaken:

- Describe the location, elevation, depth, width, flow rates, seasonal variation, flood potential, and Rhode Island state classification along the facility reach of the Pawtuxet River.
- Describe the on-site drainage patterns.
- Locate and describe the riverbed sediment depositional areas.
- Evaluate the riverbed sediment thickness profiles.
- Characterize the physical properties of riverbed sediments using grain size distribution, bulk density, cation exchange capacity, pH, porosity, and total organic carbon.

5.3 METHODS AND ANALYSES

The methods and analyses used in the hydrological investigation are described here.

5.3.1 Literature Review

The following information was available at the United States Geological Survey-Water Resources Division (USGS-WRD) office in Providence, Rhode Island, and was reviewed for the investigation:

- Average daily discharge data for the Pawtuxet River at the Cranston, Rhode Island gauging station for the Water Years 1978, and 1980 through 1987.

- Selected daily flow statistics based on the entire period of record (1941 through 1985).

- A rating table showing discharge values as functions of river stage. (Stage is defined as the elevation of the river surface above a reference point).

5.3.2 Bathymetric Survey

River reconnaissance was performed to prepare for bathymetric surveying. WCC personnel established end points for ten transects of the river, and also verified the location of outfalls to the river from CIBA-GEIGY property. The exact locations of transect end points were surveyed subsequently by Federici Associates, Inc. of Providence, Rhode Island. Verified outfalls included both surface outfalls from various SWMUs and the process water outfall from the Waste Water Treatment Plant.

A bathymetric map of the Pawtuxet River along the facility reach was generated from a survey conducted on 23 July 1990 by Ocean Surveys, Inc. (OSI) of Old Saybrook, Connecticut. WCC personnel accompanied OSI personnel during the survey. The bathymetric survey was run along ten transverse transects (shown in Figure 5-1) and one longitudinal transect. Survey equipment included a Raytheon DE-719C survey grade fathometer and a hip chain. The fathometer was calibrated by performing bar checks before and after surveying the transects. (A bar check involves positioning a stainless steel lead line at a point of known depth in the river, and adjusting the electronic signal of the fathometer to produce the correct depth on the chart recording.) Extensive aquatic macrophyte beds (weeds) obscured part or all of the fathometer output on five transects: TR-F01, TR-F02, TR-F03, TR-F05, and TR-F10. For those transects, depth was measured every 10 feet along the transects with a rod calibrated in 0.25 foot increments. The post-survey bar check indicated that drift on the fathometer was less than 0.5 feet during the survey.

5.3.3 Water Discharge Surveying

Two additional transects were established along the facility reach for water and sediment discharge monitoring. The Discharge Survey Upstream (DSU) transect is located approximately 75 feet upstream of TR-F02; the Discharge Survey Downstream (DSD) transect is located approximately 30 feet upstream of TR-F08. Important characteristics of these locations include the shape of the river channel in cross-section, the lack of turbulent eddies on the surface, and location at the upstream and downstream ends of the facility reach. The DSU and DSD transects also are shown in Figure 5-1.

Discharge was monitored at both transects on 25 July, 3 August, and 20 August 1990. At each discharge monitoring transect, a line was tied to trees on opposite banks and pulled tight to provide a tie-line. Measurement locations were established along the tie-line in accordance with the USGS mid-section method (USGS, 1977), illustrated in Figure 5-2. Reconnaissance measurements of the water velocity were taken at about 6 representative points on each transect in order to establish the measurement locations on the transect. The goal was to choose a full set of measurement locations such that in no case would the discharge of a partial section (qi) exceed 10% of the total discharge of the river flow (Q). Since the discharge of the partial sections was to be held relatively constant (10%), measurement locations were spaced widely where discharge was low, and closely where discharge was high. Despite the reconnaissance measurements, the discharge in 30 of the 72 partial sections exceeded 10% of the total river discharge, as shown in Figures 5-3 and 5-4. This outcome may have resulted from variability of flow at different stage values.

The depths at each measurement location on DSU and DSD were measured using a rod calibrated in 0.25-foot increments. The flow velocity at each measurement location was measured using a factory-calibrated Marsh-McBirney model 201 flow meter. According to USGS (1977), when total depth at a measurement location is greater than 2.5 feet, the flow velocity should be measured at two depths: at 20% and at 80% of the total depth. These measurements are averaged to obtain one flow velocity measurement for the measurement location. When total depth is less than 2.5 feet, flow velocity should be measured at 60% of the depth below the water surface (USGS, 1977). In most cases, depths at the measurement locations were greater than 2.5 feet. The river stage was recorded before and after each monitoring event at transects DSU and DSD by reading two staff gauges calibrated in 0.1-foot increments.

Total water discharge was calculated for each transect during each event using the USGS mid-section method (USGS, 1977). River discharge values generated by the USGS using this method have variable accuracy, ranging from ± 2% (considered excellent) to more than ± 8% (considered poor). The accuracy is estimated by the investigator conducting the discharge survey based on prior discharge monitoring experience (USGS, personal communication, 1990). The dynamic nature of river discharge is a main reason for uncertainty in determinations of accuracy. For this investigation, it is estimated conservatively that the accuracy of calculated discharge values is ± 10%.

5.3.4 Suspended Sediment Discharge Monitoring

Depth-integrated water samples were collected concurrently with water discharge monitoring at each of the measurement locations along DSU and DSD. The samples were collected with a peristaltic pump equipped with a flexible intake tube. Depth integration was achieved by raising the intake of the tube at a constant rate from approximately 6 inches above the river bottom to the top of the water column.

Water samples were analyzed for total suspended solids (TSS). The TSS concentration in each sample is considered representative of the TSS concentration in each partial section. Water discharge (q_i) for each partial section was multiplied by the corresponding TSS concentration to yield suspended sediment discharge (ss_i) in each partial section. Total suspended sediment discharge (SS_T) is the sum of suspended sediment discharge in all of the partial sections:

$$q_i \text{ (liters/sec) } \times TSS_i \text{ (mg/liter) } = ss_i \text{ (mg/sec)}$$

$$ss_i \text{ (mg/sec)}/1000 = ss_i \text{ (gm/sec)}$$

$$SS_T \text{ (gm/sec) } = \Sigma\,(ss_i) \text{ (gm/sec)}$$

Based on duplicate TSS analyses, estimated accuracy of the TSS results was $\pm$ 1.3 mg/l.

5.3.5 Riverbed Sediment Characterization

Riverbed sediments were collected at eight locations shown in Figure 5-1. At six of the locations (SD-F01R, SD-F01AR, SD-F02R, SD-F03R, SD-F05L, and SD-F10R), both undisturbed and disturbed samples were collected. Undisturbed samples were collected using a push core apparatus. A 10-foot length of 4-inch diameter aluminum pipe was pushed into the sediment until refusal was encountered. The pipe was filled with river water from the top and sealed at the top with a plastic cap to provide a partial vacuum during withdrawal of the core (Surface tension and the partial vacuum act to retain the sediment inside the pipe during withdrawal). The pipe was pulled out of the water quickly and sealed on the bottom with a plastic cap. A hacksaw was used to saw off the section of the pipe not filled by sediment, and then the top of the sediment core section was sealed. The top, bottom, and sample number were marked on the outside of the sealed pipe. Undisturbed samples were analyzed for porosity, bulk density, and particle size distribution.

Disturbed samples were collected in a similar manner; however, when the pipe was pulled out of the water, the sediment was extruded from the bottom of the pipe into a labelled 500 ml glass jar. Disturbed samples were analyzed for pH, cation exchange capacity (CEC), and total organic carbon (TOC).

Attempts to collect push cores at SD-F06L, SD-F07R, and SD-F08R were unsuccessful on 25 and 26 July 1990. Grab sample collection was attempted at all three of these locations on 3 August using a Shipek Model 860 grab sampler. Large cobbles became lodged in the sampler intake at SD-F06L and SD-F07R, causing loss of sample as the Shipek was hoisted through the water column. Repeated sampling attempts resulted in collection of sample sufficient only for particle size distribution analysis at SD-F06L and SD-F07R. No sample was recovered at SD-F08R despite repeated sampling attempts with the Shipek sampler. Due to the difficulties encountered during grab sampling, the particle size distributions of samples collected using this method may not be representative of the riverbed sediment.

5.4 RESULTS OBTAINED

The results of the Phase IA hydrological investigation are described here, including:

- a general description of the Pawtuxet River;
- the bathymetry of the river along the facility reach;
- water discharge in the river along the facility reach;
- suspended sediment discharge in the river along the facility reach; and
- physicochemical characteristics of sediments in the river along the facility reach.

These results are discussed more generally in Section 5.5.

5.4.1 General Description of Pawtuxet River

The Pawtuxet River and its watershed were described in detail in Volume 1, Chapters 1 and 3, of the RFI Proposal. This section summarizes the background information in that document and reviews newly acquired information concerning the river.

The Pawtuxet River basin includes approximately 230 square miles (Metcalf and Eddy, 1983). The north branch of the river (about 6 miles long) flows from the Scituate Reservoir, while the south branch (approximately 9 miles long) flows from the Flat River Reservoir. The two branches converge at River Point in West Warwick, from which point the main stem of the Pawtuxet River (about 12 miles long) flows into Pawtuxet Cove in Narragansett Bay. The main stem of the river flows through highly developed residential, industrial, and commercial areas. In addition to the two reservoir dams located at the upstream reaches of the north and south branches, flow in the Pawtuxet River is regulated by the Pawtuxet Cove Dam and multiple small mill dams throughout the length of the river.

Rhode Island state classification of Pawtuxet River water varies along the length of the river. The main stem of the river above the Cranston Sewage Treatment Plant (STP) is Class C (suitable for boating and other secondary contact recreational activities, for fish and wildlife habitat, and for industrial processes and cooling). Below the Cranston STP, the Pawtuxet River is Class D (suitable for migration of fish and has good aesthetic value).

The topographic elevations of several surface water bodies in the vicinity of the site were checked on a topographic map of the area. Pleasure Lake, Edgewood Lake, and Elmwood Lake are interconnected lakes located in Roger Williams Park. They have a water surface elevation of 29 feet above mean sea level (MSL). Fenner Pond has a surface water elevation of 23 feet. The elevation of Bellefont Pond is not shown on the map. However, it is entirely enclosed between the 10-foot and 20-foot contour lines, and therefore has a surface water elevation greater than 10 feet and less than 20 feet. The hydraulic gradient of ground water in the water table aquifer at the CIBA-GEIGY facility is toward the Pawtuxet River, and the river elevation has ranged from approximately 6.5 to 7.5 feet above MSL during the Phase IA investigation. Therefore, the Pawtuxet River appears to be the only surface water body in the area that is hydraulically downgradient of the facility.

Sedimentation rates in the Pawtuxet River have been measured by a few investigators. On the basis of anthropogenic marker compounds contained in the sediments, Avila and Hites (1979) estimated sedimentation rates of 2.1 and 3.4 cm/year for two locations (one location adjacent to the facility and the other location approximately one mile downstream of the facility). Using a similar methodology, Quinn, et al. (1985) estimated that sedimentation rates ranged from 2.4 to 2.6 cm/year in the 1960s and from 0.6 to 0.9 cm/year in the 1970s. They attributed the decrease in sedimentation rate to cessation of construction activities associated with Interstate Highway 95.

The USGS Cranston stream gauge has a period of record from 1941 to 1985 (data from more recent years is not yet in the computer data base at the USGS-WRD office in Providence). The time-duration curve for the Pawtuxet River at Cranston for the period

1941 to 1985 is shown as Figure 5-5. Low and high extremes for mean monthly discharge are 75 cubic feet per second in July 1957 and 1788 cubic feet per second in April 1983, respectively. Geographic limits of the 100-year floodplain of the Pawtuxet River in the vicinity of the facility are shown in Chapter 1 of the RFI Proposal (Volume 1).

The Providence USGS-WRD has generated a rating table for the Pawtuxet River at the Cranston gauge that relates discharge to river stage (i.e., elevation of the river surface). The period of record is 1941 to 1985. Figure 5-6 is a rating curve plotted from selected values from the rating table. The curve has a distinct break in slope at a discharge of approximately 600 cfs. This break in slope may represent a fundamental change in flow conditions, such as flooding beyond the banks of the river.

Releases to the Pawtuxet River from the Scituate Reservoir have varied over time. Wright and McCarthy (1985) reported that 18 to 20 million gallons per day (mgd) were released over a period of 4 to 8 hours every day except Sunday. The manager at the Scituate Plant informed WCC personnel in September 1990 that releases are now made continuously, amounting to approximately 1 mgd except during springtime periods of heavy rain and runoff.

5.4.2 Bathymetry of the Pawtuxet River along the Facility Reach

The bathymetry of the Pawtuxet River along the facility reach as recorded on 23 July 1990 is shown on Figure 5-1. It shows the depth contours (with 0 depth equivalent to approximately 6.4 feet elevation above mean sea level), location of outfalls, riverbed sediment sample locations, and the position of the water discharge monitoring cross-sections DSU and DSD.

Water depth in the Pawtuxet River along the facility reach ranges from 2 to 9 feet. The depth contours clearly show the development of pools (deeper areas) and riffles (shallower areas). Pools are developed in areas where the channel narrows, indicating that higher-velocity waters may be scouring the riverbed sediment. In general, pools reflect erosional processes, whereas riffles indicate deposition or resistance to erosion due to riverbed sediment resistance or presence of rooted plants.

General morphologies of the water discharge monitoring transects DSU (Discharge Survey Upstream) and DSD (Discharge Survey Downstream) can be inferred from the bathymetric map. DSD exhibits a fairly uniform morphology, deepest in the middle and shallowing toward either bank. In contrast, DSU is characterized by two channels near each bank separated by a shoal in the middle of the transect. The morphology of DSU is not optimal for discharge monitoring, but it represented the best possible monitoring transect at the upstream end of the facility reach.

5.4.3 Water Discharge in the Pawtuxet River along the Facility Reach

Water discharge was monitored at DSU and DSD on 25 July, 3 August, and 20 August, 1990. Table 5-1 summarizes the discharge results.

The survey on 25 July was preceded by rainy weather. Rainfall records at T.F. Green Airport in Warwick show that 0.53 inches fell on July 24 and 0.55 inches fell on July 25. Because the weather cleared by noon on July 25, 1.08 inches of rain fell in the (roughly) 36-hour period preceding the discharge survey. The river stage increased about 1 foot during the night of July 24/25. Therefore, the results of this survey are considered representative of higher flow conditions. The calculated water discharge was 337 cubic feet per second (cfs) at DSU and 382 cfs at DSD. Based on the USGS-WRD daily flow statistics, the discharges measured on 25 July 1990 at DSU and DSD are greater than 65 to 70% of the daily flows observed at the USGS Cranston gauge over the period of record (1941 to 1985). The discharge increases by approximately 45 cfs from DSU to DSD, a difference amounting to about 12% of the total discharge.

Discharge monitoring on 3 August was preceded by a week of dry weather, so the results are likely to represent low flow conditions. The calculated water discharge was 138 cfs at DSU and 130 cfs at DSD. The discharge values are greater than only 20 to 22% of the daily discharge values at the Cranston gauge over the period of record. The discharge calculations indicate a slight decrease in river discharge from DSU to DSD. However, the decrease in discharge from DSU to DSD (about 8 cfs) is only about 6% of the discharge calculated at either DSU or DSD. This 6% difference is within the ± 10% error estimated by WCC personnel for the stream discharge monitoring. As a result, it is interpreted that the difference between discharges at DSU and DSD was not measurable on 3 August.

Rain, with an associated rise in the river stage, began while DSU and DSD were being monitored on 20 August. The calculated water discharges of 147 cfs at DSU and 190 cfs at DSD were somewhat higher than the corresponding values from 3 August. These discharge values are greater than 25 to 39% of the daily discharge values at the USGS-WRD Cranston gauge over the period of record. The river discharge on 20 August fell between the discharges on 25 July and 3 August. Discharge increased by 43 cfs from DSU to DSD. This downstream gain is a 29% increase from the total discharge measured at DSU.

The stage-discharge relationships derived from the three monitoring events were compared to the corresponding section of the USGS rating curve for the gauge on the Pawtuxet River at Cranston, as shown in Figure 5-7. The lines for DSU and DSD resemble closely the line for the USGS rating curve.

5.4.4 Suspended Sediment Discharge in the Pawtuxet River along the Facility Reach

Suspended sediment discharge values for DSU and DSD during all three monitoring events are presented in Table 5-1. At DSU, suspended sediment discharge ranged from 10 to 158 grams/sec (0.85 to 13.4 long tons/day). At DSD, the range was 3 to 218 grams/sec (0.26 to 18.5 long tons/day). These values represent the mass of suspended sediment passing the measurement locations per second at the time of surveying. (Suspended sediment concentrations in individual samples ranged from not detected (less than 3 mg/l) to 22 mg/l.) Figure 5-8 shows suspended sediment discharge as a function of water discharge for both DSU and DSD. Under the water discharge conditions observed during the three monitoring events, the suspended sediment discharge increases exponentially with increased water discharge as would be predicted because of the higher sediment carrying capacity of the river under increased flow conditions.

5.4.5 Physicochemical Characteristics of Sediments in the Pawtuxet River along the Facility Reach

Riverbed sediments were obtained by push coring and grab sampling. (The sampling locations are shown on Figure 5-1.) The field descriptions and recoveries for each sediment sample are given in Table 5-2. Table 5-3 gives analytical results for cation exchange capacity, pH, total organic carbon, dry bulk density, and porosity for the riverbed sediment samples. This section describes the results for each analyte.

Grain size distribution curves for each sample are shown in Appendix E. These results were produced from grain size analyses that were incomplete. In addition, the values for porosity and dry bulk density (given in Table 5-3) are questionable because the analytical methodology used may not be appropriate for riverbed sediments. Therefore, the results of the geotechnical analyses (porosity, dry bulk density, and grain size distribution) must be considered as preliminary.

Cation exchange capacity (CEC) values are very low, ranging from not detected to 8 milliequivalents/100 grams. A compilation of CEC values for different materials is shown in Table 5-4, supporting the conclusion that riverbed sediments from the Pawtuxet River have extremely low cation exchange capacity.

The pH values of the riverbed sediment samples were all slightly acidic, ranging from 5.42 to 6.00. These values are expected for a sediment composed of siliciclastic sand and/or gravel with little or no buffering soil components (such as carbonate minerals derived from limestone or dolomite).

Total organic carbon (TOC) results range from 110 to 20,000 mg/kg (i.e., 0.01 % to 2.0 % by weight). Gilham, et al. (1980) reported on fifteen unconsolidated geologic samples that had TOC concentrations ranging from 0.03 to 2.05% by weight. The TOC content of riverbed sediments in the Pawtuxet River appears to be within the range for natural materials.

5.5 DISCUSSION

The results of the hydrological investigation are discussed more generally in this section.

5.5.1 Calculation of Ground Water Discharge to the Pawtuxet River along the Facility Reach

The Pawtuxet River is a gaining stream (i.e., the discharge of the river increases in the downstream direction). This description of the river is documented by water levels in the water table aquifer that are higher in elevation than the river surface (cf. Section 4.0 of this report). Therefore, ground water in the water table aquifer flows downward to the river. The cause of increased discharge in a downstream direction in a gaining stream is that ground water discharge from the watershed augments the flow of the river.

When there are no rainfall or runoff surface contributions to the discharge of a river, the river is considered to be under base flow conditions. Under base flow conditions, all water discharge increases from DSU to DSD would be attributable to ground water discharge alone. During rain, discharge increases from DSU to DSD will be caused by a variable combination of rainfall, runoff, and ground water discharge.

The river probably was not affected by rainfall or runoff on 3 August because there was no rain in the area; therefore, the river appeared to be under base flow conditions. The decrease in water discharge from DSU to DSD on 3 August (Table 5-1) reflects the effect of error in the discharge measurements. Theoretically, discharge decreases in the downstream direction indicate recharge of the aquifer by the river. However, the difference in discharge measurements at DSU and DSD on 3 August is less than 10% of the total discharge and is regarded as error variance. If true base flow conditions prevailed, these results suggest that the amount of ground water discharge from the facility cannot be measured by comparing stream discharge values at the upstream and downstream ends of the facility reach. In summary, the discharge difference between DSU and DSD was within error variance on 3 August and was close to error variance on 25 July. On 20 August, the increase in discharge from DSU to DSD was probably affected by rain and a slight increase in stage.

On 25 July and 20 August 1990, the amount of discharge gain from DSU to DSD was 45 cfs and 43 cfs, respectively. However, both of these monitoring events were affected by rain. Therefore, it is likely that these results do not reflect base flow conditions. The downstream increase in discharge may be attributed to ground water discharge, direct rainfall on the river, runoff from the facility, and (possibly) stage increases occurring while discharge monitoring was taking place. It is impossible to establish with confidence the relative contributions of these factors. It is likely, however, that ground water discharge accounted for a only a fraction of the discharge increases observed on 25 July and 20 August. Based on the data gathered during river discharge monitoring, ground water discharge along the facility reach of the Pawtuxet River probably is not measurable by stream discharge monitoring.

The amount of ground water discharge to the river per unit area of watershed along the facility reach was estimated. Wright and McCarthy (1985) reported that the amount of drainage basin added to the river from Elmwood Avenue to the Warwick Avenue bridge is 3.0 square miles. The distance from Elmwood Avenue to Warwick Avenue includes the CIBA-GEIGY facility reach and is roughly three times longer than the facility reach. Therefore, the assumption that all 3 square miles of watershed are added along the facility reach is very conservative. Assuming that the water table aquifer in glacial outwash sediments yields 1 million gallons per day to the river per square mile of contributing watershed (USGS-WRD, Providence, RI, personal communication), the amount of ground water discharge along the facility reach is predicted to be 3 mgd, or 4.6 cfs. Assuming 10% error variance, total stream discharge would have to be 46 cfs or less to permit resolution of a difference of 4.6 cfs between DSU and DSD. The time duration curve in Figure 5-5 shows that total discharge at the Cranston gauge exceeds 46 cfs at least 99% of the time. Therefore, the river conditions required to detect a difference of 4.6 cfs occur only 1% of the time.

Another way of estimating the amount of ground water discharge to the Pawtuxet River along the facility reach is to use measured aquifer properties such as hydraulic conductivity and saturated thickness. Slug tests conducted as part of the Phase IA hydrogeological investigation yielded an average hydraulic conductivity (k) approximately equal to 200 gallons per day per square foot (gpd/ft^2; see Table 4-3). Multiplying k by saturated thickness of the aquifer (b) gives transmissivity (T) in gallons per day per foot. The hydrogeological investigation suggested that b, the saturated thickness of the aquifer at the site, is a maximum of 50 feet. Transmissivity is the amount of groundwater discharge through a section of the aquifer measuring one foot by one foot by the thickness of the aquifer over a unit drop in head (Fetter, 1980). In fact, the highest drop in head observed at the facility was 0.100 feet per horizontal foot, so transmissivity must be multiplied by 0.100 to give the ground water discharge for a part of the aquifer measuring 1 foot by 1 foot by 50 feet. Finally, the facility reach is approximately 0.5 mile or 2640 feet long. Therefore, the transmissivity value for a part of the aquifer measuring 1 foot by 1 foot by 50 feet should be multiplied by 2640 feet.

$$200 \text{ gpd/ft}_2 \times 0.100 \text{ ft/ft} \times 50 \text{ ft} = 1000 \text{ gpd/ft}$$
$$1000 \text{ gpd/ft} \times 2640 \text{ ft} = 2{,}640{,}000 \text{ gpd}$$
$$2{,}640{,}000 \text{ gpd}/1{,}000{,}000 = 2.64 \text{ million gallons/day}$$
$$2.64 \text{ mgd} = 4.1 \text{ cfs}$$

The value of 4.1 cfs is applicable to the aquifer on one side of the Pawtuxet River. To calculate the ground water discharge to the river from both sides of the river, 4.1 cfs must be multiplied by 2, so 8.2 cfs is the expected ground water discharge to the Pawtuxet River based on measured aquifer properties.

The calculation of aquifer transmissivity assumes that all ground water discharge is horizontal. This assumption is not valid for the water table aquifer at the CIBA-GEIGY site because vertical gradients were observed in several nested pairs of piezometers. Therefore, some of the ground water included in the 200 gpd/ft^2 actually flows upward and will not discharge to the river until some later time. Finally, boring logs indicate that a saturated thickness of 50 feet is a maximum, and that most locations at the facility are characterized by smaller saturated thicknesses. Therefore, the estimate of 8.2 cfs for ground water discharge to the Pawtuxet River along the facility reach may be a high estimate.

To summarize, the three estimates of ground water discharge to the Pawtuxet River along the facility reach, based on the different estimation methods described here, are as follows:

Stream discharge monitoring estimate -- unmeasurable

Watershed characteristics-based estimate -- 4.6 cfs

Aquifer properties-based estimate -- 8.2 cfs (maximum)

Comparison of these estimates indicates that actual ground water discharge along the facility reach probably cannot be quantified using river discharge monitoring methods.

5.5.2 Comparison of Calculated Water Discharge along the Facility Reach to the USGS Instantaneous Discharge Values at Cranston

Instantaneous discharge values at the USGS stream gauge at Cranston are calculated by the USGS using the rating table and measurements of river stage collected automatically every hour, on the hour. These instantaneous discharge values from the USGS gauge at Cranston were compared to the instantaneous discharge values calculated as part of the Phase IA investigation as shown in Table 5-5.

For 25 July and 20 August, the instantaneous discharge values at the Cranston gauge are considerably larger than the values calculated at the facility reach. On 25 July, the rainy conditions affecting discharge measurements at the facility appear to have affected the river at the Cranston gauge to a much greater degree. A heavy downpour at the Cranston gauge may have caused the large increase in stage and discharge. However, this large increase in discharge would have arrived at the facility reach only after a period of several hours. It is possible that discharge at the facility reach increased to approximately 500 cfs after the discharge monitoring activities were complete on 25 July. A similar sequence of events may have produced the higher instantaneous discharge values at the Cranston gauge on 20 August. The cause of the variability is the highly localized nature of summer rain and thunderstorms.

For 3 August, the instantaneous discharge values at the Cranston gauge are slightly lower than those calculated for the transects along the facility reach. The river appeared to be under base flow conditions on 3 August because there had been virtually no rainfall since 25 July. Therefore, the slight increase (3-10%) in flow downstream probably indicates ground water contribution to the river between the USGS gauge at Cranston and the facility reach.

5.5.3 Erosion and Deposition of Sediment in the Pawtuxet River along the Facility Reach

The flow regime of a river refers to a range of streamflows exhibiting similar bedforms, resistances to flow, and modes of sediment transport. Essentially, flow regime is a classification scheme to describe conditions of sediment erosion, transport, or deposition in a river. The flow regime in the Pawtuxet River along the facility reach can be described either based on bedforms observed on the river bottom or based on calculation of the Froude number because flow regime, bedforms, and the Froude number are interrelated (Morisawa, 1968). The Froude number is defined as

$$F=\frac{V}{\sqrt{gD}}$$

where V = mean velocity, g = gravitational constant, and D = depth. When $F << 1$ (much less than 1.0, lower flow regime), flow is tranquil and ripples are formed on the bed. When $F < 1$ (less than 1.0, lower flow regime), flow is somewhat faster and dunes are formed on the riverbed. When $F > 1$ (greater than 1.0, upper flow regime), flow is rapid enough to form plane beds. Finally, when $F >> 1$ (much greater than 1.0, upper flow regime), antidunes are formed.

No bedforms were observed on the fathometer output during bathymetric surveying of the Pawtuxet River along the facility reach. (If bedforms were present, their height would have been less than 0.5 feet. That is, due to drift in the calibration of the fathometer, bedforms less than 0.5 feet high may have been missed.) Therefore, evaluation of the flow regime of the river by observation of bedforms was not possible. Instead, the Froude number was calculated.

The most conservative way to evaluate flow regime (and, in turn, the potential bedload transport of contaminated sediments) is to calculate the Froude number using the highest observed stream velocity. The highest stream velocity observed was recorded on 25 July on DSD. The mean velocity was 1.12 ft/sec; the river was 8.80 feet deep at this location. Using a value of 981 cm/sec^2 as the gravitational constant, the Froude number is 0.07. Because $F = 0.07$ is much less than 1, flow in the Pawtuxet River is in the lower part of the lower flow regime. At most, ripples would be the expected bedform.

The nature of the riverbed sediment also must be considered relative to the potential transport of contaminants on the sediment. The sediments are characterized by low CEC and TOC, indicating that the likelihood of adsorption of contaminants on the sediments is low. In addition to the relatively low potential for adsorption of contaminants on the sediments, the suspended sediment discharge is quite low. With the exception of the silt at SD-F03R, the median grain size of all the riverbed sediment samples is in the range of sand and gravel. Miller, et al. (1977) determined values of the flow velocity at 1.0 meter above the bed that were required to initiate movement of quartz-density grains at 20° C. The values range from 0.9 feet/sec for very fine-grained sand to 2.6 feet/sec for granules (gravel). Since 1.12 feet/sec was the maximum mean flow velocity observed during the investigation, it is concluded that bedload transport of sediment is minimal in the Pawtuxet River along the facility reach under the conditions observed during the investigation.

The relatively low amounts of silt and clay in the riverbed sediments and the relatively low suspended sediment discharge may be caused by flow regulation of the Pawtuxet River. Gregory and Walling (1973) report that reservoirs are often used for studies of basin sediment yield, because accretion of sediment in a reservoir directly reflects the sediment yield of the tributary watershed. The water released from any given reservoir is therefore relatively free of suspended material. Because river flow velocities downstream of the reservoir may support a considerable suspended sediment load, it is likely that suspended material will be "pirated" from the riverbed. Ultimately, the riverbed loses the finer-grained material, leaving a coarser-grained lag deposit as the riverbed sediment. This process could account for the loss of fine grains documented in the grain size profiles for many of the riverbed sediments (Appendix E), and may be applicable to the Pawtuxet River along the facility reach.

Based on the conditions observed during this investigation, erosion, transport, and redeposition of sediment in the Pawtuxet River appear to be minimal at this time, possibly due to flow regulation. The suspended load is low, the riverbed sediment is mostly coarse-grained, and flow velocities are insufficient to resuspend all but the silt-sized sediment.

The data, and inferences drawn from the data, appear to be somewhat inconsistent with sedimentation rates reported in the literature for the Pawtuxet River. There are at least two explanations for this inconsistency. The most important factor is that conditions in the watershed have changed. For example, construction of Interstate Highway 95 probably affected the amount of suspended sediment in the river. Construction of several shopping centers may have decreased the sediment yield and increased the runoff from the watershed. The conditions described for the Phase IA investigation represent current conditions only.

Another explanation for the apparent inconsistency is that published sedimentation rates were calculated using a methodology that is probably inappropriate for river sedimentation. The estimates of sedimentation rates were based on the position of anthropogenic marker compounds in sediment cores. In addition, the sediment cores were collected near the banks of the Pawtuxet River. The position of marker compounds in the sediment can be controlled by numerous erosion and redeposition cycles and bioturbation. Use of anthropogenic marker compounds for dating sediment in a river (in contrast to a lake) yields highly questionable results. Therefore, published sedimentation rates are not representative of conditions in the main channel of the river. It is possible that erosion is taking place in the main channel concurrently with sedimentation along the channel margins. These considerations resolve the apparent inconsistency between published sedimentation rates and the Phase IA investigation results.

Flood conditions were not observed during the investigation. It is likely that significant erosion, transport, and redeposition of riverbed sediment occurs during flood events on the Pawtuxet River.

5.6 SUMMARY

The Phase IA hydrological investigation of the Pawtuxet River along the CIBA-GEIGY facility reach indicates that:

- o Facility reach depths range from 2 to 9 feet, and bathymetry indicates the presence of pools and riffles.

- o Stream discharge ranged from 130 to 382 cubic feet per second (cfs) during the investigation.

- o Suspended sediment discharge under the observed flow conditions ranged from 0.26 to 18.5 long tons/day.

- o Riverbed sediments are composed of sands and gravels except at TR-F02 and TR-F03, where silts are present. All sediment samples exhibit low cation exchange capacity, total organic carbon, and pH.

- o Under base flow conditions (3 August); the instantaneous discharge values of the river at the USGS Cranston gauge compare well with the values calculated at the facility. On 25 July and 20 August, however, the comparison is probably invalid due to the effects of variable rainfall along the Pawtuxet River.

- o Estimates of ground water discharge to the river along the facility reach vary from being unmeasurable to 8.2 cfs. Given the underlying assumptions made for each estimate, it is likely that the actual ground water discharge to the facility reach is less than the amount that can be quantified using river discharge monitoring.

Most of the goals of the hydrologic investigation were met during the Phase IA investigation.

- o The location, elevation, depth, width, flow rates, and Rhode Island state classification of the Pawtuxet River were described. Seasonal variation of conditions in the river was not quantified because the investigation took place only during July and August.

- o Flood potential of the river was documented in Volume I of the RFI Proposal.

- o On-site drainage patterns were not observed during Phase IA. However, this goal will be carried into the Phase IB investigation.

- o It was not possible to define riverbed sediment depositional areas based on the bathymetry of the river along the facility reach, because riffles may reflect resistance to erosion (rather than deposition). The low Froude number and suspended sediment discharge rates appear to indicate very low sedimentation rates under the flow conditions observed during the investigation.

- o The thickness of riverbed sediment was not resolved by the fathometer used for bathymetric surveying. Push core recoveries were 17 inches or less, so the riverbed sediment is at least 17 inches thick in some areas.

- o Physical properties of the riverbed sediment were described.

- Seasonal variation in suspended sediment and bed sediment transport was not documented because the investigation took place only during July and August. A low Froude number and the relatively large grain size of the riverbed sediment indicates that bedload transport was minimal during the investigation. Suspended sediment transport also was low. The Phase IA investigation documented that suspended sediment discharge increases with increased water discharge.

The results of the Phase IA investigation of the Pawtuxet River along the facility reach do not warrant any significant change in the revised work plan for the release characterization to be conducted during Phase IB. Eleven riverbed sediment samples will be collected using a hand corer device at the locations shown in Figure 5-9. The cores will be driven a maximum of 1 foot into the riverbed. Recovery may be less than 1 foot depending on the nature of the sediment. If coring is not feasible due to the presence of gravel, grab sediment samples will be collected with a grab sediment sampler. The variation of grain size across the river channel will be evaluated by collecting five additional samples for particle size analysis (along a transect to be established during the Phase IB investigation). Surface water dip samples will be collected at seven locations (shown in Figure 5-9).

Sediment samples and surface water samples will be analyzed for the constituents of concern in Table 4-5 in Volume I of the Facility Investigation Work Plan. In addition, surface water dip samples will be analyzed for total suspended sediment. If the sediment samples are gravelly, the chemical analysis for metals and major ions will not be possible, and the results of organic compound analysis may be biased in an unquantifiable way due to inhomogeneity in the sample.

TABLE 5-1. DISCHARGE SUMMARY TABLE FOR THE PAWTUXET RIVER
CIBA-CEIGY FACILITY, CRANSTON, RHODE ISLAND

DATE	*DISCHARGE SURVEY UPSTREAM ("DSU")*				*DISCHARGE SURVEY DOWNSTREAM ("DSD")*			
	WATER DISCHARGE (cfs)	*% OF TIME DISCHARGE EQUALLED OR EXCEEDED ***	*ELEVATION OF CLOSEST STAFF GAUGE (feet)*	*SUSPENDED SEDIMENT DISCHARGE (gram/sec)*	*WATER DISCHARGE (cfs)*	*% OF TIME DISCHARGE EQUALLED OR EXCEEDED ***	*ELEVATION OF CLOSEST STAFF GAUGE (feet)*	*SUSPENDED SEDIMENT DISCHARGE (gram/sec)*
7/25/90	337	35%	7.48	158	382	30%	7.19	218
8/3/90	138	78%	6.54	10	130	80%	6.41	3
8/20/90	147	75%	6.70	15	190	61%	6.68	24

** This category is based on USGS computer calculations of daily flow statistics for the Pawtuxet River, with a period of record ranging from 1941 to 1985.

cfs = cubic feet per second.

Done by MD, checked by CM

TABLE 5-2. SEDIMENT DESCRIPTIONS, MEDIAN GRAIN SIZE, AND CRITICAL VELOCITY TO INITIATE PARTICLE MOVEMENT
PAWTUXET RIVER
CIBA-GEIGY FACILITY
CRANSTON, RHODE ISLAND

SAMPLE NUMBER	FIELD DESCRIPTION	RECOVERY (inches)	MEDIAN GRAIN SIZE (mm)	UDDEN-WENTWORTH CLASSIFICATION OF MEDIAN GRAIN SIZE*	CRITICAL VELOCITY TO INITIATE PARTICLE MOVEMENT** (ft/s)
SD-F01R	Brown gravelly sand with thin layer of silty sand at sediment-water interface.	10	3.9	GRAVEL/granule	4.6
SD-F01AR	Brown medium-coarse sand with gravel.	17	0.25	SAND/medium	1.6
SD-F02R	Dark brown silty sand with hydrocarbon odor.	13	0.16	SAND/fine	1.2
SD-F03R	Dark brown silty sand with hydrocarbon odor.	16	0.062	SILT/coarse	1.0
SD-F05L	Gray medium-coarse sand.	9	0.58	SAND/coarse	1.9
SD-F06L***	Brown gravel to cobbles with some sand.	NA	16	GRAVEL/pebble	6.2
SD-FO7R***	Brown gravel to cobbles with some sand.	NA	31	GRAVEL/pebble	8.9
SD-F10R	Brown gravelly sand with some silt. Some roots and leaves.	10	2.1	GRAVEL/granule	2.7

* REFERENCE: Leeder (1982)
** REFERENCE: Miller et al (1977)
*** Grab samples collected with Shipek sampler.
NA = not applicable

Done by MD, checked by CM

TABLE 5-3. ANALYTICAL RESULTS FOR RIVERBED SEDIMENT SAMPLES
PAWTUXET RIVER
CIBA-GEIGY FACILITY
CRANSTON, RHODE ISLAND

SAMPLE IDENTIFIER	*DATE OF COLLECTION*	*CATION EXCHANGE CAPACITY (meq/100 g)*	*pH (standard) (units)*	*TOTAL ORGANIC CARBON (mg/kg)*	*DRY BULK DENSITY (pcf)*	*POROSITY (%)*
SD-F01R	7/26/90	ND	5.42	110	98.1	34.5
SD-F01AR	7/26/90	ND	5.52	440	101.0	32.5
SD-F02R	7/25/90	5	6.00	9900	54.6	60.2
SD-F03R	7/25/90	ND	5.79	20000	47.6	61.3
SD-F05R	7/25/90	8	5.58	290	91.1	39.1
SD-F10R	7/25/90	1	5.69	1900	89.3	42.7

Note:
1. All samples were also analyzed for particle size distribution.
2. SD-F06L and SD-F07L were analyzed for particle size distribution only.

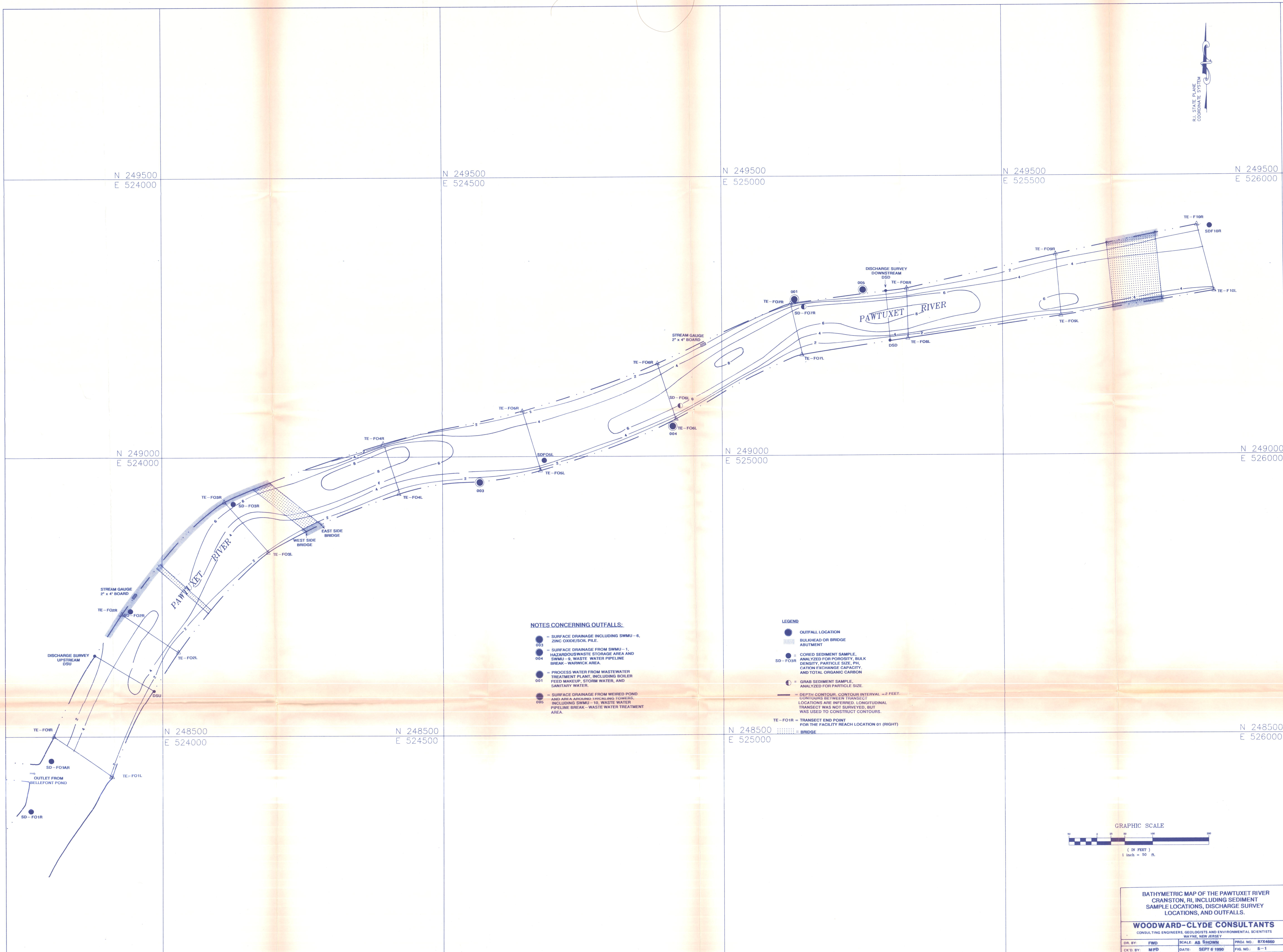
ND = not detected

Done by MD, checked by CM

TABLE 5-4. TYPICAL VALUES OF CATION EXCHANGE CAPACITY (CEC) FOR SELECTED MATERIALS

MATERIAL	CATION EXCHANGE CAPACITY (meq/100 grams)
Kaolinite*	3 to 15
Illite*	10 to 40
Chlorite*	10 to 40
Smectite (montmorillonite)*	80 to 150
Vermiculite*	100 to 150
Soil organic matter**	>200
Sand**	2 to 7
Sandy loam**	2 to 18
Loam**	8 to 22
Silt Loam**	9 to 27
Clay Loam**	4 to 32
Clay**	5 to 60

* = Grim (1968)
** = Dragun (1988)



R.I. STATE PLANE COORDINATE SYSTEM
N 249500
E 524000
N 249500
E 524500
N 249500
E 525000
N 249500
E 525500
N 249500
E 526000
N 249000
E 524000
N 249000
E 525000
N 249000
E 526000
N 248500
E 524000
N 248500
E 524500
N 248500
E 525000
N 248500
E 526000
PAWTUXET RIVER
PAWTUXET RIVER
TE-F10R
SDF10R
TE-F10L
TE-FO9R
TE-FO9L
DISCHARGE SURVEY DOWNSTREAM DSD
TE-FO8R
TE-FO8L
DSD
005
001
TE-FO7R
SD-FO7R
TE-FO7L
STREAM GAUGE 2" x 4" BOARD
TE-FO6R
SD-FO6L
TE-FO6L
004
TE-FO5R
SDFO5L
TE-FO5L
003
TE-FO4R
TE-FO4L
TE-FO3R
SD-FO3R
WEST SIDE BRIDGE
EAST SIDE BRIDGE
TE-FO3L
STREAM GAUGE 2" x 4" BOARD
TE-FO2R
SD-FO2R
TE-FO2L
DISCHARGE SURVEY UPSTREAM DSU
DSU
TE-FOIR
SD-FO1AR
OUTLET FROM BELLEFONT POND
TE-FO1L
SD-FO1R
NOTES CONCERNING OUTFALLS:
003 = SURFACE DRAINAGE INCLUDING SWMU-6, ZINC OXIDE/SOIL PILE.
004 = SURFACE DRAINAGE FROM SWMU-1, HAZARDOUS WASTE STORAGE AREA AND SWMU-9, WASTE WATER PIPELINE BREAK-WARWICK AREA.
001 = PROCESS WATER FROM WASTEWATER TREATMENT PLANT, INCLUDING BOILER FEED MAKEUP, STORM WATER, AND SANITARY WATER.
005 = SURFACE DRAINAGE FROM WEIRED POND AND AREA AROUND TRICKLING TOWERS, INCLUDING SWMU-10, WASTE WATER PIPELINE BREAK-WASTE WATER TREATMENT AREA.
LEGEND
OUTFALL LOCATION
BULKHEAD OR BRIDGE ABUTMENT
SD-FO3R = CORED SEDIMENT SAMPLE, ANALYZED FOR POROSITY, BULK DENSITY, PARTICLE SIZE, PH, CATION EXCHANGE CAPACITY, AND TOTAL ORGANIC CARBON
= GRAB SEDIMENT SAMPLE, ANALYZED FOR PARTICLE SIZE.
= DEPTH CONTOUR. CONTOUR INTERVAL =2 FEET. CONTOURS BETWEEN TRANSECT LOCATIONS ARE INFERRED. LONGITUDINAL TRANSECT WAS NOT SURVEYED, BUT WAS USED TO CONSTRUCT CONTOURS.
TE-FO1R = TRANSECT END POINT FOR THE FACILITY REACH LOCATION 01 (RIGHT)
= BRIDGE
GRAPHIC SCALE
0
25
50
100
200
(IN FEET)
1 inch = 50 ft.
BATHYMETRIC MAP OF THE PAWTUXET RIVER CRANSTON, RI, INCLUDING SEDIMENT SAMPLE LOCATIONS, DISCHARGE SURVEY LOCATIONS, AND OUTFALLS.
WOODWARD-CLYDE CONSULTANTS
CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS
WAYNE, NEW JERSEY
DR. BY: FWD
SCALE: AS SHOWN
PROJ. NO.: 87X4660
CK'D. BY: MPD
DATE: SEPT 6 1990
FIG. NO.: 5-1

TABLE 5-5. COMPARISON OF INSTANTANEOUS DISCHARGE: VALUES CALCULATED AT THE FACILITY REACH (DSU and DSD) COMPARED TO VALUES FROM THE USGS STREAM GAUGE AT CRANSTON

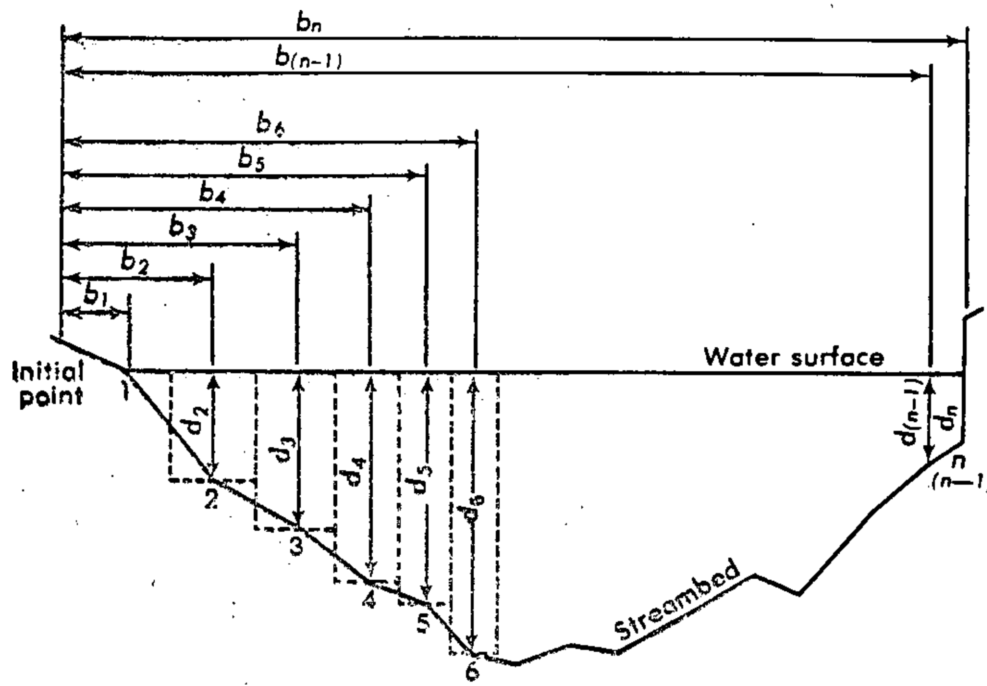
DATE	TIME	INSTANTANEOUS DISCHARGE AT DSU* (Cubic feet per second)	INSTANTANEOUS DISCHARGE AT USGS CRANSTON GAUGE (Cubic feet per second)	DIFFERENCE BETWEEN USGS CRANSTON AND FACILITY REACH** (Cubic feet per second)
7/25/90	1100	337	592	-255
8/3/90	1800	138	123	15
8/20/90	1100	147	226	-79

DATE	TIME	INSTANTANEOUS DISCHARGE AT DSD* (Cubic feet per second)	INSTANTANEOUS DISCHARGE AT USGS CRANSTON GAUGE (Cubic feet per second)	DIFFERENCE BETWEEN USGS CRANSTON AND FACILITY REACH** (Cubic feet per second)
7/25/90	1300	382	538	-156
8/3/90	1700	130	126	4
8/20/90	1300	190	252	-62

* DSU denotes 'Discharge Survey Upstream', a monitoring transect established along the facility reach.
DSD denotes 'Discharge Survey Downstream, a monitoring transect established along the facility reach.

** Negative discharge differences reflect a sign convention. When discharge is greater at the USGS Cranston gauge than at the facility reach, the discharge difference is negative.

Done by MD, checked by CM



EXPLANATION

1,2,3..........n	Measurement locations
$b_1, b_2, b_3 \ldots\ldots b_n$	Distance, in feet, from the initial point to the measurement location
$d_1, d_2, d_3 \ldots\ldots d_n$	Depth of water, in feet, at the measurement location
Dashed lines	Boundary of partial sections

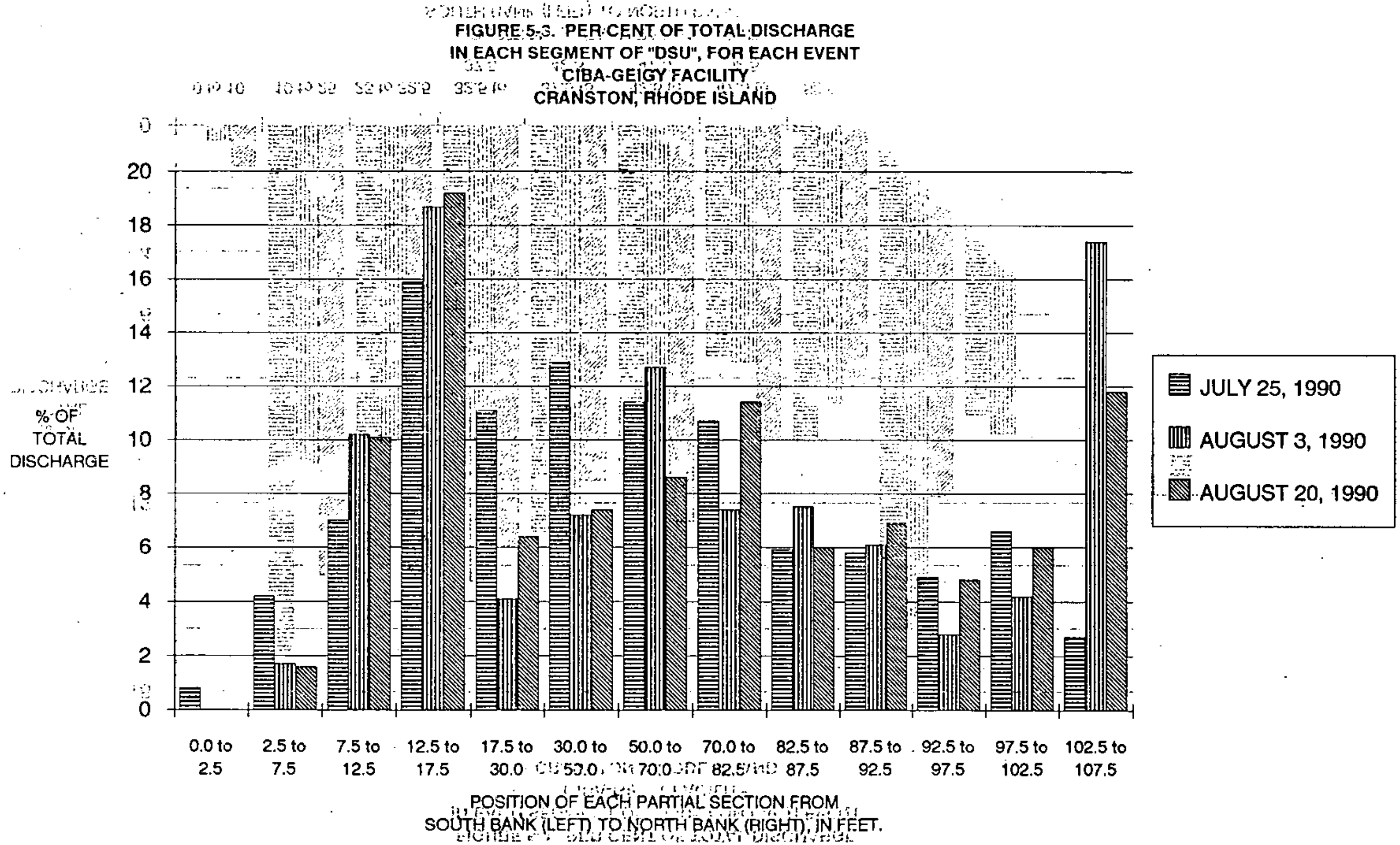
Area of a partial section (A_i): $a_4 = \left(\frac{b5-b3}{2}\right) d4$

Discharge of a partial section (q_i): $q_4 = a_4 V_4$

where V= mean velocity at b_4

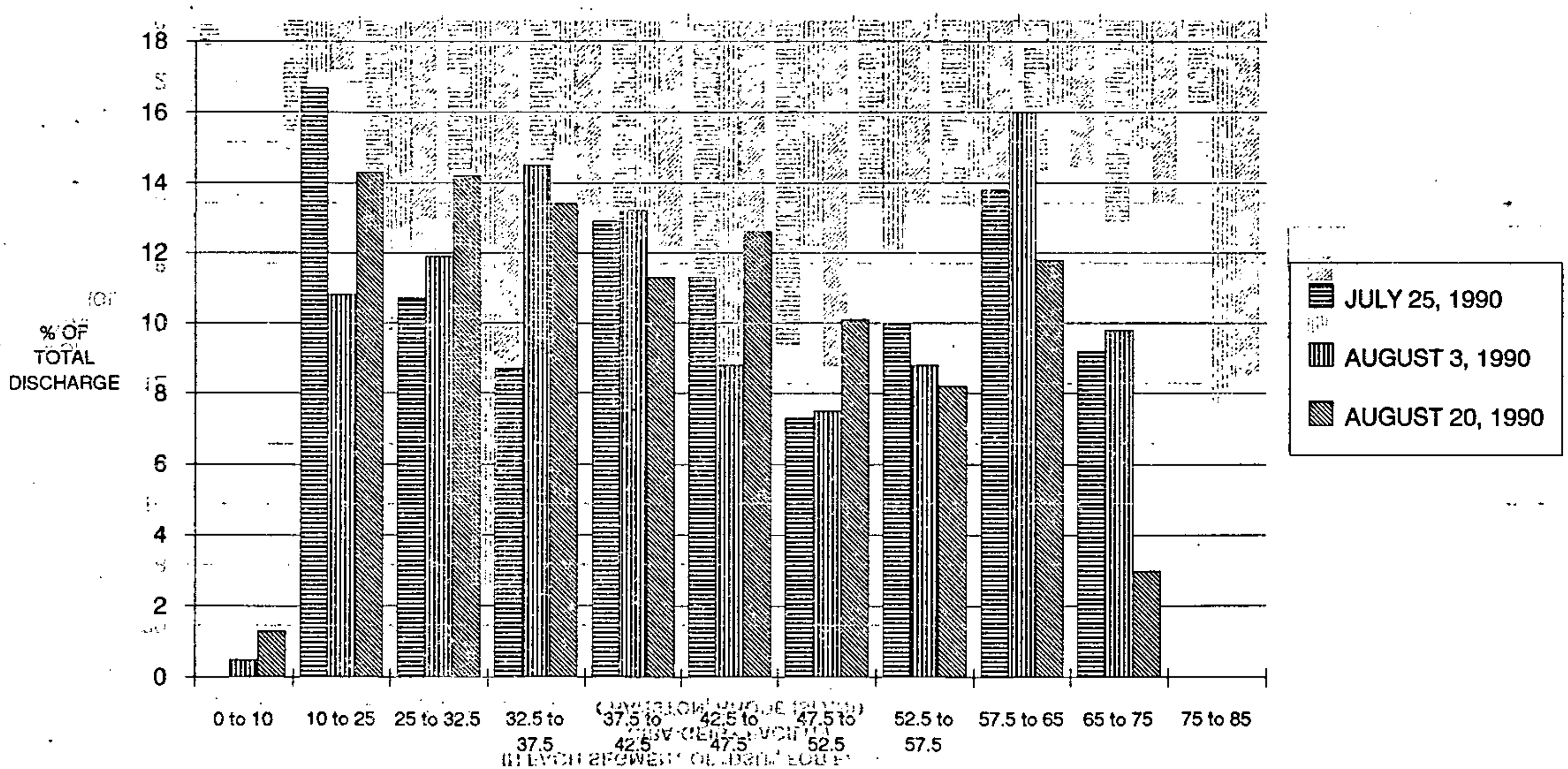
Discharge of the river (Q): $Q = \sum (q_1 + q_2 + q_3 + \ldots q_n)$

UNITES STATES GEOLOGICAL SURVEY MID-SECTION METHOD FOR CALCULATION OF DISCHARGE. FROM U.S.G.S. (1977)					
WOODWARD-CLYDE CONSULTANTS CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS WAYNE, NEW JERSEY					
DR. BY:	BAS	SCALE:	NONE	PROJ. NO.:	87X4660
CK'D. BY:	MD	DATE:	17 SEPT 1990	FIG. NO:	5-2



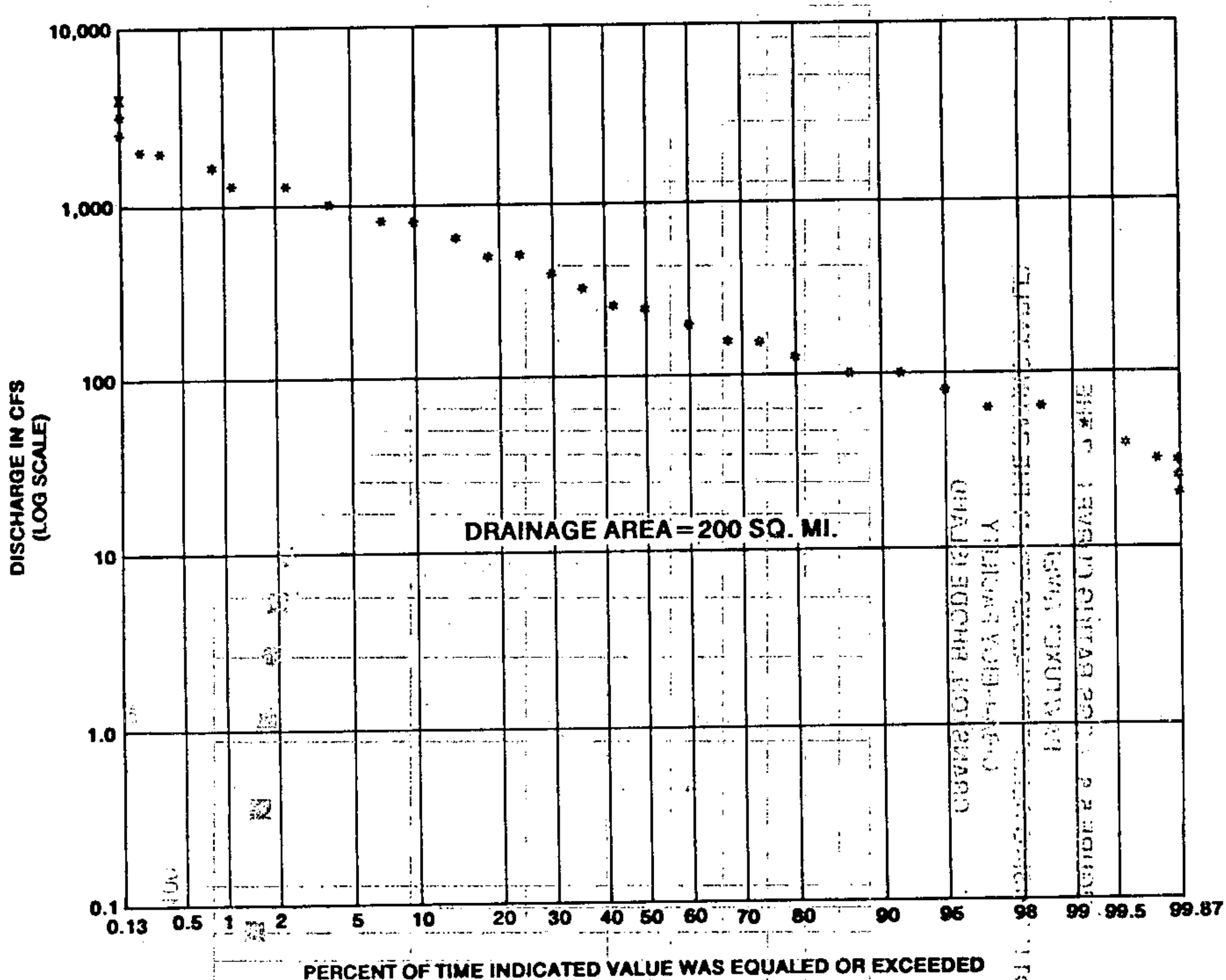
Done by MD, checked by CM

FIGURE 5-4. PER CENT OF TOTAL DISCHARGE
IN EACH SEGMENT OF "DSD", FOR EACH EVENT
CIBA-GEIGY FACILITY
CRANSTON, RHODE ISLAND



POSITION OF EACH PARTIAL SECTION FROM
SOUTH BANK (LEFT) TO NORTH BANK (RIGHT), IN FEET.

Done by MD, checked by CM



NOTES:

1. PERIOD OF RECORD IS FROM 1941 TO 1985.
2. SQ. MI. = SQUARE MILES
3. * = SINGLE POINT
4. x = MULTIPLE POINTS

SOURCE:

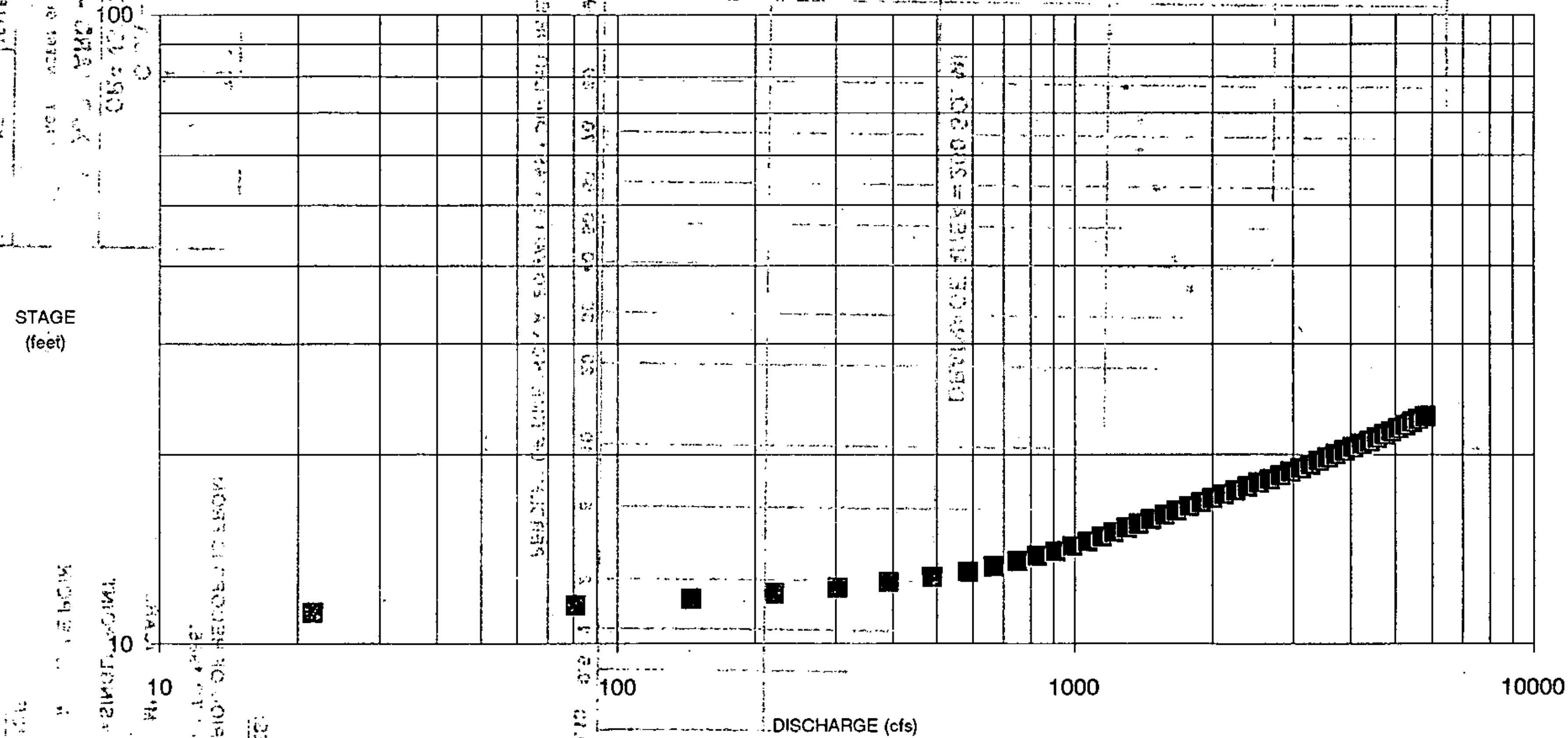
USGS, 1990

TIME DURATION CURVE
PAWTUXET RIVER DISCHARGE
CRANSTON, RHODE ISLAND
CIBA–GEIGY FACILITY
CRANSTON, RHODE ISLAND

WOODWARD – CLYDE CONSULTANTS
CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS
WAYNE, NEW JERSEY

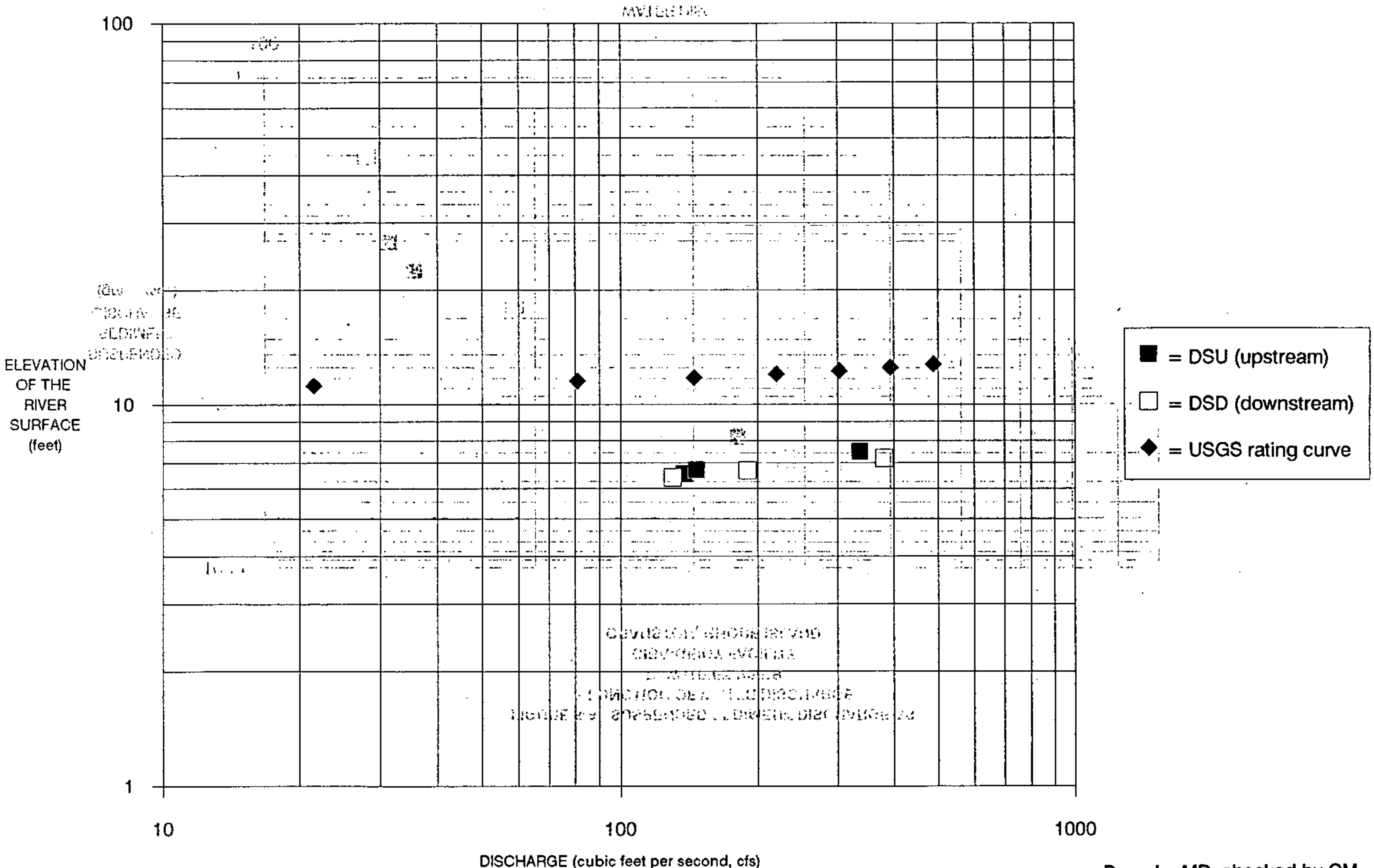
DR. BY: KF	SCALE: AS SHOWN	PROJ. NO.: 87X4660
CK'D. BY: CWT	DATE: 19 SEPT 1990	FIG. NO.: 5–5

FIGURE 5-6. USGS RATING CURVE FOR THE PAWTUXET RIVER
(PLOTTED USING SELECTED VALUES FROM THE RATING TABLE)
CIBA-GEIGY FACILITY
CRANSTON, RHODE ISLAND



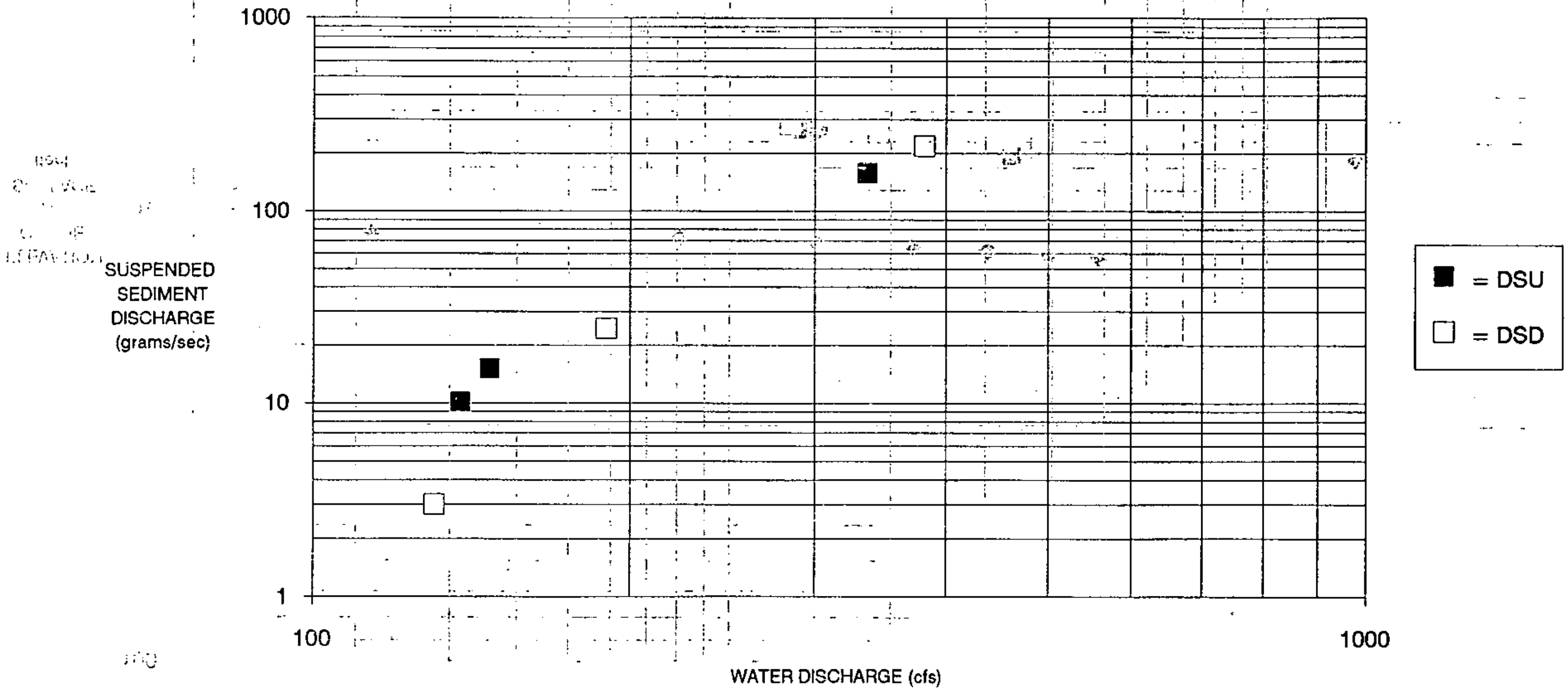
Done by MD, checked by CM

FIGURE 5-7. COMPARISON OF THE USGS RATING CURVE TO THE RATING CURVES FOR DSU AND DSD
CIBA-GEIGY FACILITY
CRANSTON, RHODE ISLAND

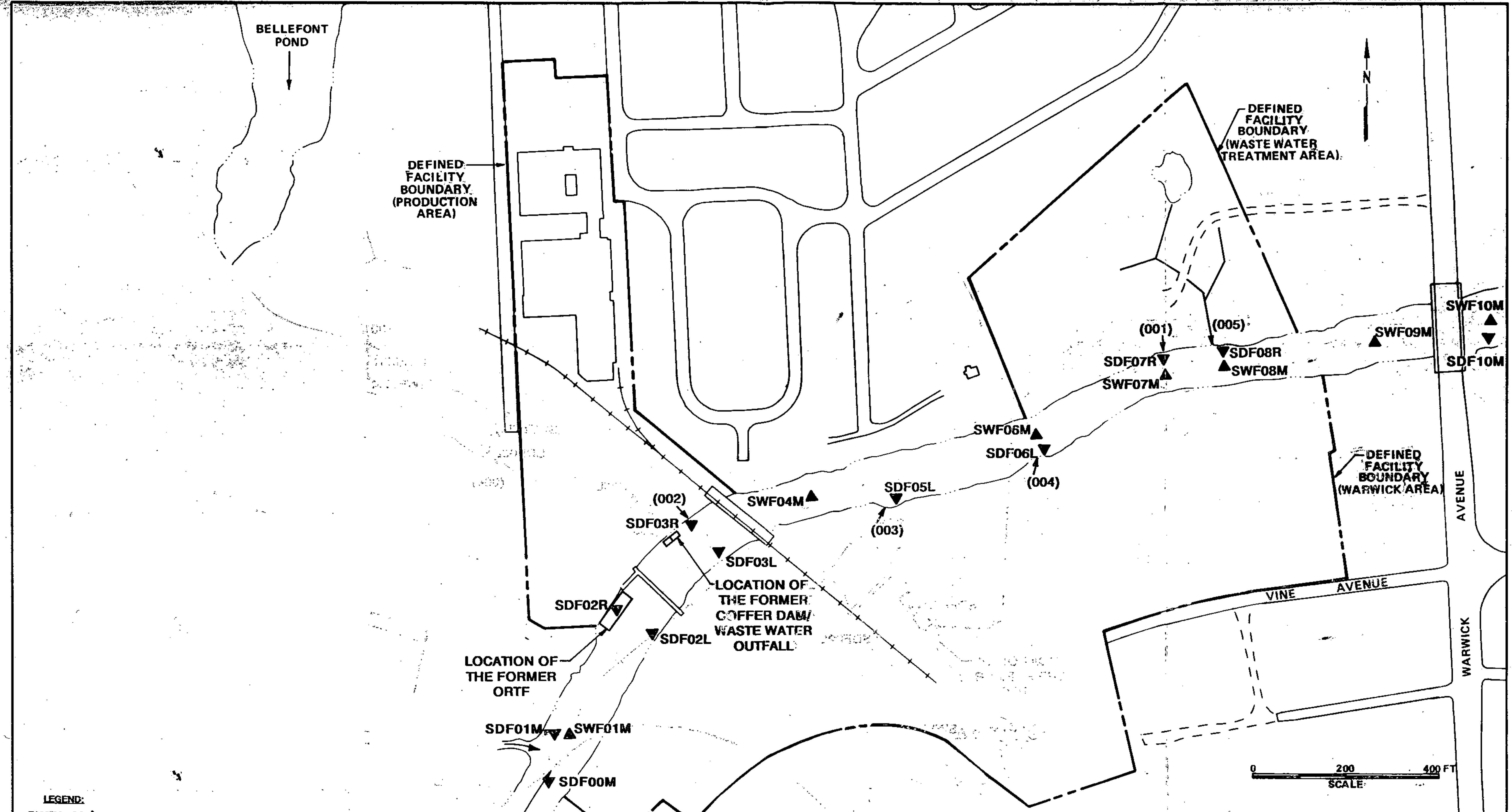


Done by MD, checked by CM

FIGURE 5-8. SUSPENDED SEDIMENT DISCHARGE AS A FUNCTION OF WATER DISCHARGE
PAWTUXET RIVER
CIBA-GEIGY FACILITY
CRANSTON, RHODE ISLAND



Done by MD, checked by CM



LEGEND:

SWF01M ▲ SURFACE WATER SAMPLE
SDF02R ▼ BED SEDIMENT SAMPLE
(001) → FORMER OUTFALL
ORTF OVER THE RIVER TANK FARM

NOTE:

LOCATIONS SHOWN ARE APPROXIMATE. THE LOCATIONS WILL BE FINALIZED BASED ON INFORMATION OBTAINED DURING THE CONDUCT OF THE HYDROLOGIC STUDY.

BASE MAP SOURCE:

GEOD CORPORATION OF NEWFOUNDLAND, NEW JERSEY. MAPPED BY PHOTOGRAMMETRIC METHODS FROM AERIAL PHOTOGRAPHS. DATE FLOWN: 2 APRIL 1989.

PROPOSED SURFACE WATER AND BED SEDIMENT SAMPLING LOCATIONS
CIBA–GEIGY FACILITY
CRANSTON, RHODE ISLAND

WOODWARD – CLYDE CONSULTANTS
CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS
WAYNE, NEW JERSEY

DR. BY: KF	SCALE: 1:2400	PROJ. NO.: 87X4660
CK'D. BY: PN	DATE: 19 SEPT 1990	FIG. NO.: 5-9

REVISED SEPT. 7, 1990

Section Six

SECTION 6

CONCLUSIONS, IMPACT OF THE PHASE IA RESULTS, AND RECOMMENDATIONS FOR ADDITIONAL WORK

6.1 OVERVIEW

This section presents the conclusions and impacts of the Phase IA investigations and recommends further work. It has five subsections. The conclusions are presented in Section 6.2 and are based on the results of the physical characterization tasks described in Sections 2 through 5. The impact of the Phase IA results on the Phase IB investigation is discussed in Section 6.3. Recommendations for additional work (not included in the RFI Work Plan) are presented in Section 6.4. Section 6.5 is a summary.

6.2 CONCLUSIONS

Geophysical Results. The following conclusions were drawn from the results of the three geophysical surveys:

1. The depth to bedrock beneath the facility averages 50 to 60 feet.

2. The average depths to bedrock in the three study areas were as follows:

    - Production Area - 50-60 feet below land surface;
    - Waste Water Treatment Area - 45-60 feet below land surface; and
    - Warwick Area -- 60 feet below land surface.

3. A dense till of varying thickness overlies the bedrock.

4. The average thicknesses of till in the study areas were as follows:

- o **Production Area** -- 10-15 feet;
- o Water Treatment Area -- 10-30 feet; and
- o Warwick Area -- 20-30 feet.

5. The overburden deposits, which consisted of fine sands, silts, clays, and some gravels, were characterized by gradational facies changes in both the vertical and horizontal dimensions.

6. Ground-penetrating radar (GPR) was not successful in discriminating subsurface features at the site.

7. Electrical resistivity was a more effective method than seismic refraction in differentiating bedrock, till, and individual units of the overburden deposits.

Geological Results. The following conclusions were drawn from the results of the geological investigation:

1. Bedrock beneath the facility consists of partially metamorphosed sandstones and shales, consistent with lithologies of the Rhode Island Formation.

2. Till was encountered in several borings.

3. The variable nature of the overburden deposits is consistent with a glaciofluvial and/or fluvial deposition.

4. The overburden deposits are more complex than anticipated based on the Phase IA results and on previous data. Individual units appear to be discontinuous both vertically and horizontally.

5. Good correlations were made between the boring data and the electrical resistivity data.

6. Till and bedrock have similar seismic velocities and cannot be distinguished reliably by the seismic refraction method. Higher-density deposits overlie lower density deposits. Hence, the seismic refraction method is not the geophysical method of choice for differentiating the overburden soils, till, and bedrock at the site.

<u>Hydrogeological Results</u>. The following conclusions were drawn from the results of the hydrogeological investigation:

1. In the bedrock aquifer, there is a net upward potential gradient at three locations and a downward potential gradient at one location.

2. There are significant upward potential gradients within the overburden.

3. Apparent horizontal potential gradients were determined as follows:
   - <u>bedrock aquifer</u> -- .003 to .005;
   - <u>deep overburden aquifer</u> -- .02 to .1; and
   - <u>shallow overburden aquifer</u> -- .013 to .1.

<u>Hydrological Results</u>. The following conclusions were drawn from the results of the hydrological investigation:

1. Discharge values calculated from the three discharge monitoring events fall within the 30th and 70th percentile range of the discharge frequency statistic reported for the USGS gauge at Cranston, Rhode Island.

2. Working rating curves were developed for the transects at this site.

3. Relatively low concentrations of suspended sediment were detected at both the DSD and DSU transects at all three observed flow conditions.

4. Bed sediment is primarily sands and gravels except along the bulkhead where samples were finer-grained.

5. No bedforms having amplitudes greater than six inches were observed.

6. The Froude number calculated for the maximum flow rate observed indicates that the observed river conditions are within the lower flow regime. Therefore, bedload sediment transport rates appear to be low under the conditions observed. The monitoring events did not include flood conditions.

6.3 IMPACT OF PHASE IA

Sampling locations for the Phase IB investigation are presented in Figures 6-1 and 6-2. Details of the Phase IB investigation are presented in the RFI Work Plan (Volume 1, Chapter 3, Section 4). The Phase IA results suggest the following impacts on the Phase IB investigation:

- o No major modifications to the sampling strategy proposed for the release characterization (Phase IB) are required.

- o Minor locational changes are recommended for monitoring wells intended to be downgradient of specific releases. Downgradient locations will be based on our current (13 September 1990) water table contour map.

- o Screen settings also will be modified based on our current understanding of site stratigraphy and on boring data.

o Anomalous headspace results were detected in soil samples from boring P-21D. Because these hits could not be attributed to known past facility releases or methane interferences, soil samples from a boring near P-21D will be analyzed for Appendix IX volatile organic compounds.

6.4 RECOMMENDATIONS FOR FURTHER WORK

Review and evaluation of the Phase IA results identified new data gaps. Additional characterization studies are recommended to provide a better understanding of the facility's physical environment. Recommendations for additional work (not included in the RFI Work Plan) are presented here.

Geological Needs

o Three additional continuous sample borings will be advanced to define better the facility's stratigraphy in more detail. One boring will be located in the northwest corner of the Waste Water Treatment Area; the other borings will be located in the western section of the Warwick Area (as shown in Figure 6.1).

o Off-site, two additional borings will be advanced to help evaluate the hydrostratigraphic conditions at the facility. The borings will be located north and west of the Waste Water Treatment Area (as shown in Figure 6.1).

o Soil samples from borings will be tested in the laboratory to differentiate between fine-grained (silts) and very fine-grained (clay) materials. Every other soil sample from borings advanced in Phase IB will be analyzed for grain size.

- To classify soils better in Phase IB, all soil samples submitted for geotechnical analysis also will be tested for Atterberg limits (and moisture content).

Hydrogeological Needs

- On-site, the new stratigraphic borings will be completed as deep piezometers. A shallow piezometer will be installed also at the southern Warwick Area location but not at the other locations where they currently exist (as shown in Figure 6-2). These nested piezometer pairs will provide data needed to characterize further the ground water flow directions and hydraulic potential gradients.

- Off-site, the stratigraphic borings will be completed as deep piezometers. Shallow monitoring wells will also be installed at the locations to evaluate background water quality.

- To evaluate the site hydraulics better, the following tasks will be performed:

  - In Phase IB, all existing monitoring wells and piezometers will be rehabilitated.
  - Water level measurements will be taken monthly, not quarterly.

- Long-term automatic ground water level monitoring will be performed in a few selected wells in the Production Area.

- Small-scale step-drawdown tests will be performed in the Production Area.

- Short-term constant rate pump tests will be performed on selected wells in the Production Area (rate and duration to be determined from step-drawdown).

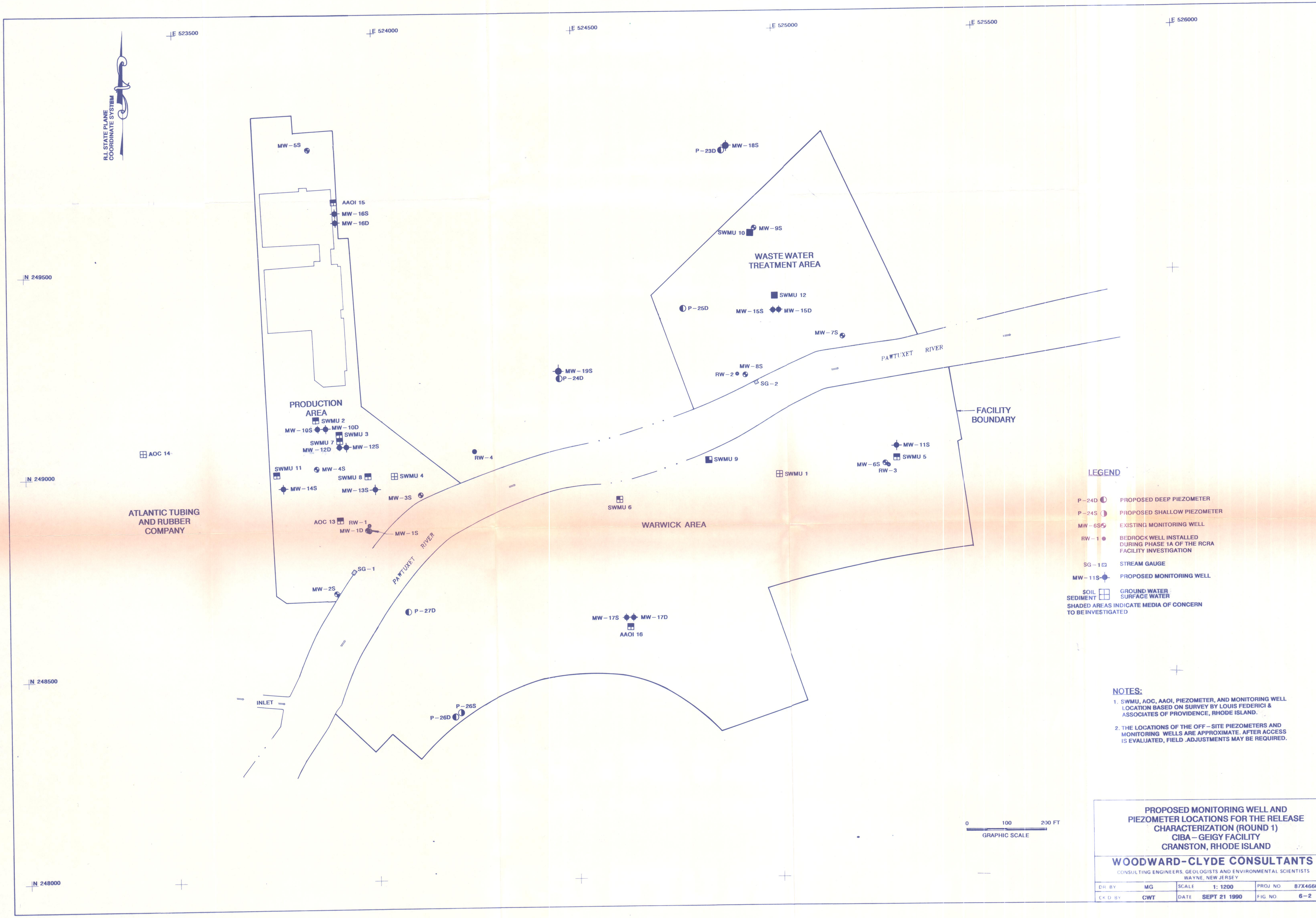
NOTES:

1. SWMU, AOC, AND AAIO LOCATIONS BASED ON SURVEY BY LOUIS FEDERICI & ASSOCIATES OF PROVIDENCE, RHODE ISLAND.
2. THE LOCATIONS OF THE OFF-SITE BORINGS ARE APPROXIMATE. AFTER ACCESS IS EVALUATED, FIELD ADJUSTMENTS MAY BE REQUIRED.

PROPOSED SOIL BORING AND TEST PIT LOCATIONS FOR THE RELEASE CHARACTERIZATION (ROUND 1)
CIBA-GEIGY FACILITY
CRANSTON, RHODE ISLAND

WOODWARD-CLYDE CONSULTANTS
CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS
WAYNE, NEW JERSEY

DR BY	MG	SCALE	1: 1200	PROJ NO	87X4660
CK'D BY	CWT	DATE	SEPT 21 1990	FIG NO	6-1



NOTES:

1. SWMU, AOC, AAOI, PIEZOMETER, AND MONITORING WELL LOCATION BASED ON SURVEY BY LOUIS FEDERICI & ASSOCIATES OF PROVIDENCE, RHODE ISLAND.
2. THE LOCATIONS OF THE OFF-SITE PIEZOMETERS AND MONITORING WELLS ARE APPROXIMATE. AFTER ACCESS IS EVALUATED, FIELD ADJUSTMENTS MAY BE REQUIRED.

PROPOSED MONITORING WELL AND PIEZOMETER LOCATIONS FOR THE RELEASE CHARACTERIZATION (ROUND 1)
CIBA-GEIGY FACILITY
CRANSTON, RHODE ISLAND

WOODWARD-CLYDE CONSULTANTS
CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS
WAYNE, NEW JERSEY

DR BY	MG	SCALE	1: 1200	PROJ NO	87X4660
CK D BY	CWT	DATE	SEPT 21 1990	FIG. NO.	6-2

Wells will be determined after Phase IB monitoring wells are installed and the first sampling is completed.

Hydrological Needs

- o All surface water samples collected from the Pawtuxet River during Phase IB will be analyzed for total suspended solids (TSS). Addition of this analyte will enable integration of chemical analytical results with the suspended sediment characteristics of the water samples.

6.5 SUMMARY

This section presented the conclusions from the Phase IA investigation, the impact on the Phase IB investigation, and recommendations for additional work. Overall, no major modifications to the Phase IB investigation are required, but a number of minor modifications for additional work are recommended.

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